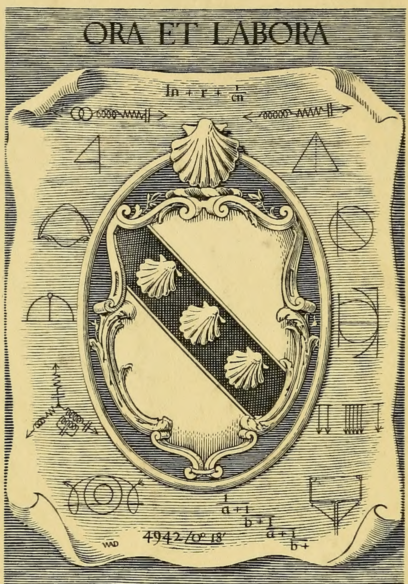
The Practical Telephone Handbook

THE SPECIALISTS' SERIES

TELFORD

J. Poole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THE PRACTICAL TELEPHONE HANDBOOK

View of South Wing of the National Telephone Co.'s Gerrard Street London Exchange

This Exchange, opened September 1907, is equipped for 9520 Subscribers' Lines
1269 Incoming Junction Lines
1520 Outgoing ,, ,,
103 Subscribers' Operators' Positions
47 Junction ,, ,,

THE PRACTICAL
TELEPHONE HANDBOOK

AND

GUIDE TO THE TELEPHONIC EXCHANGE

BY

JOSEPH POOLE, A.M.I.E.E.

Whitworth Scholar

Technical Staff, Head Office, National Telephone Co. Ltd.

WITH 530 ILLUSTRATIONS

FOURTH EDITION

Revised and Enlarged

THE MACMILLAN CO.

64 AND 66 FIFTH AVENUE, NEW YORK

WHITTAKER & CO., LONDON

PREFACE TO THIRD EDITION

THE remarkable development in the art and practice of telephony which has taken place during the last decade, and more especially during the last five years, has necessitated the complete rewriting and rearranging of the edition of this book published in 1895. The present edition has more than twice the amount of letterpress matter, nearly 200 more illustrations, and the size of the page is enlarged. Such enlargement has been needed owing to the greatly increased scope of the art, which has followed from the general adoption of central-energy methods of working exchanges, and the greater complexity of the plant. It is, perhaps, not too much to say that, within the period mentioned, there has been a greater revolution than has taken place in any other technical business in the same time.

The apparatus used, especially that in exchanges, has, to a large extent, now become standardised, so that whilst in the future there will, no doubt, be many improvements, those made will, it is believed, more likely be in connection with smaller details than with the general principles, unless some very great advance in automatic exchange working should lead to its general adoption, which, however, is not considered likely by the writer.

This standardisation, and the general adoption of central-energy working, has led to a more scientific study and treatment of the problems involved, especially in connection with traffic and the designing of exchanges.

The necessities of central-energy working and the line-loading arrangements of Professor Pupin and others have also led to more definite appreciation of the value of the best line construction, and to the better designing of lines for economical transmission.

In the book the writer has chiefly confined himself to British practice, and mainly to that of the National Telephone Company. This, in most particulars, is now the same as American practice, which, so far, has nearly always kept to the

front. A special feature has been made of central-energy working, which although not yet universal in this country is rapidly becoming so. Whilst following the National Company's practice the writer has endeavoured to deal in an unprejudiced manner with other systems. Any opinions expressed must be taken as entirely his own.

Speaking generally, only instruments, etc., practically in use have been described, but exceptions have been made where some special principle is illustrated in the apparatus described.

The very large scope of the art has rendered it necessary to adopt the division-of-labour principle, and divide the staff into various classes, as it is almost impossible for any one man to make himself familiar with all the various branches. These divisions are such as: Overhead Engineering; Underground Engineering; Switch-board Equipment; Testing Department; Investigation Department; Traffic Department; Operating Department, etc.

The writer has endeavoured to touch on all the engineering departments, but he cannot pretend that he has done so exhaustively, as it would be altogether out of the question for such a work as this is intended to be. The Table of Contents will give an idea of the actual scope of the work.

The portion of the agreement, recently entered into between the Post Office and the National Telephone Co., relating to transmission tests (see Appendix) has excited much interest, and is likely to lead to decided progress in the way of the better designing of lines, etc.

The writer takes this opportunity of very heartily thanking those of his colleagues who have kindly assisted him, including Mr G. W. Shepherd, who has given special assistance with Chapter XXVI. on Long-Distance Working; Mr E. A. Laidlaw, Mr T. Fletcher, Mr B. S. Cohen, and several others. He has also to acknowledge his indebtedness to the National Telephone Company for permission to make use of drawings, blocks, etc., from the excellent and extensive series of Engineering Circulars and "Correspondence Class-Books" issued by them, of which permission full advantage has been taken. He is very particularly indebted to his friend Mr F. W. Shorrocks for the great assistance he has rendered, and the large amount of trouble he has taken in making drawings, and correcting the manuscript and proofs.

He is much indebted to the Western Electric Company (who have supplied most of the apparatus for central-energy

working in this country) for the loan of blocks, and for photographs of the Barnsbury Exchange, etc.; to the British Ericsson Company for the loan of blocks; to Messrs Nalder Brothers, the Chloride Electrical Storage Company, Messrs Shippey Brothers, Messrs Evershed & Vignoles, and others for similar assistance.

He has also to acknowledge the permission of the proprietors of *The Electrician* to use blocks of Figs. 169, 171, 172, 188, 189, 268, 269, 270, 274, 299, 300, and 392*a*. These are mostly from the excellent books on the Post Office exchanges published by this firm, and he is indebted to the proprietors of *The Electrical Review* for their kind permission to use Figs. 323, 464, and 467.

The writer has availed himself of illustrations from some of the excellent American periodicals, such as *Telephony*, *The American Telephone Journal*, and others.

J. P.

London, *November* 1905.

PREFACE TO THE FOURTH EDITION

SINCE the publication of the last edition of this work in 1906 the great strides which have been made in the progress of the art of telephony have necessitated considerable revision and the addition of four new chapters—viz. Submarine Telephone Cables, The British Insulated Co.'s Telephone Work and Later Post Office Practice, Development Studies, and Wireless Telephony. The inclusion of these four chapters and other additions has increased the size of the volume by seventy pages and some sixty illustrations.

The most extensive revision has been made in the chapters on C.B. Switch-Boards and Junction-Line Working, Aerial Line Construction, Underground Work, Long-Distance Lines and Pupin System (the writer is again much indebted to Mr G. W. B. Shepherd for the addition of much interesting matter to this chapter), and Special Exchange Systems. Certain small matters which it was found impossible for various reasons to include in their respective chapters, have been placed in the Appendix.

In making the additions it has been the aim of the author to deal with those matters which are of general interest to telephone workers and users, somewhat to the exclusion of those subjects appealing to certain sections of workers only. It is, therefore, hoped that the book will be recognised as a good general review rather than an exhaustive treatise on the subject.

The author again expresses his indebtedness to many of his colleagues, more especially to Mr G. W. B. Shepherd, Mr E. A. Laidlaw, Mr J. Shea, and Mr W. Napier; to the editors of *Telephony* (Chicago) and *The National Telephone Journal* for the use of matter of which he has freely availed himself; and also to the proprietors of *The Electrician*, *The Electrical Review*, *Electrical Engineering*, and *Post Office Electrical Engineers' Journal*, and other firms who have lent blocks for the illustrations, and to the National Telephone Co. for permission to use drawings, blocks, etc.

J. P.

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Practical Telephone Handbook

CHAPTER I

INTRODUCTORY

As the subject of Telephony, of which this book is to treat, needs for its elucidation at least an elementary knowledge of electrical science, and in order that the book may be serviceable to the general public, it is considered advisable to define the various electrical terms which will be met with in the descriptive matter, and to give a short sketch of the science. Telephone employees, for whom the book is chiefly intended, are expected to possess this knowledge, for the acquisition of which such means as evening classes, or the various correspondence classes carried on by the National Telephone Company, offer every opportunity—the latter, of course, being available only to those in the Company's service.

Electricity.—Certain peculiar effects which bodies exhibit under certain circumstances when acted upon by friction, chemically, by heat, etc., are said to be due to a charge of electricity imparted to the bodies. When thus electrified, bodies possess the property of attracting light objects, such as pieces of paper, and, under certain circumstances, of repelling light bodies, and also of exhibiting sparking effects.

Two Kinds of Electricity.—It has also been discovered that there are two kinds of electricity, which are always produced together. They act in certain ways similarly to each other, and in other ways oppositely to each other, so that one kind neutralises the effect of the other. One of these kinds is produced on, say, the substance rubbed, and the other on the

rubber. Very often the latter kind may escape, and evidence of its presence be lost, but it will be somewhere in close proximity to the other charge. The kind of electricity produced on glass when it is rubbed with silk is called *positive*, and that produced on the silk, or on amber, sealing wax, and other resinous bodies, when they are rubbed with flannel, is called *negative*. Bodies charged with the same kind of electricity *repel* each other, and those charged with opposite kinds attract each other.

Insulators and Conductors.—The electric charge on some bodies, such as glass, sealing wax, etc., appears to adhere to that part which has been rubbed; whilst on other bodies such as metals, the charge moves freely over the body from one part to another. The former are called *insulators*, and the latter *conductors*. Some substance of the former class must be used to insulate the conductors when the latter are required to retain an electric charge, or the electricity immediately escapes, combines with its opposite kind, and is neutralised.

Potential.—The intensity of the effects produced by a charge of electricity is proportional to what is termed the *potential* of the electric charge above that of the surrounding bodies—a term which expresses the amount of work which the electricity is capable of doing in combining with its opposite kind, and so becoming neutralised. It may be considered an analogous term, or quality, to that of "pressure" in the case of steam, or of height in the case of a reservoir of water.

Electric Current.—When any two points of a conducting body are charged with electricity at different potentials, a movement of electricity takes place over or through the conducting medium until the whole is brought to a common potential. This movement of electricity caused by *difference of potential* (usually designated by the letters P.D.) gives rise to certain effects in and about the conductor—such as heat, attraction and repulsion, magnetism, chemical changes, etc.—and these effects are said to be due to an *electric current* passing through the conductor. As *electric* currents are the only

currents that will be dealt with in this book, no misunderstanding should arise if the term *electric* is dropped.

Strength of a Current.—This is measured by the magnitude of the effects produced in a given time.

Resistivity.—An infinite variety of strengths of current may be obtained by including different substances, and different masses of these substances, in the path of a current. The cause of the various strengths is due to the different *resistances* which these materials oppose to electricity in motion.

All bodies offer some resistance, which is found to be in direct proportion to the length of any material of uniform section and quality, and inversely proportional to the area of section or to the square of its diameter. Resistance also varies with the temperature of the material, that of metallic bodies increasing with a rise of temperature, and that of non-metallic bodies decreasing, of some, such as carbon, very markedly.

Conductivity.—Substances, such as the metals, which offer the least resistance, are called good conductors, or are said to have a *good conductivity.* This quality is, therefore, the converse of resistivity.

Of the metals, pure silver and copper offer the least resistance. If that offered by a piece of pure copper is taken as the unit, the resistivities of pieces of the same size of the more common metals and other substances, at the same temperature, will be approximately as follows:—

Pure silver	0·94	Pure lead	12·29
Pure copper	1·00	German silver	13·1
Pure aluminium	1·82	Platinoid	20·8
Pure platinum	5·67	Manganin	30·3
Pure iron	6·08	Pure mercury	59·55
Pure tin	8·27		

Carbon	1400 to 40,000
Dilute sulphuric acid ($\frac{1}{12}$th acid)	1,940,000
Pure water	41,300,000
Glass	14,000,000,000,000 or 14×10^{12}
Gutta-percha	700,000,000,000,000,000,000 or 7×10^{20}

Insulators.—From this list it will be seen that glass and gutta-percha offer an enormous resistance to the passage of the current; therefore these, and substances such as porcelain, india-rubber, and ebonite, are selected to confine the current to a certain path, by using them as coverings or supports to the conducting materials. They are, therefore, called insulators, and are of great importance in practical electrical matters.

Potential Difference.—The strength of the current which can pass through a path of a certain resistance depends upon the P.D. between the ends of that path. This is analogous to the case of two reservoirs of water at different heights joined together by a pipe. The greater the difference between the two levels the stronger will be the current of water through the pipe, and the more work any certain weight of water in the higher reservoir would be able to perform in falling to the lower. Potential is sometimes called *electrical pressure*, and may be looked upon as the *urging* power of electricity.

Electro-motive Force.—Any contrivance which can produce a P.D. is said to have an *electro-motive force*, which term is usually abbreviated to E.M.F. There are many ways of producing such a P.D.—as by means of voltaic batteries, heat, magneto-electric machines, etc.

Volt.—Differences of potential and electro-motive forces are compared by reference to a practical unit called the *volt*, which is a little less than the E.M.F. of a Daniell cell (1·065 volts). A new Leclanché cell has an E.M.F. of 1·46 volts.

The *Ohm* is the unit in terms of which all measurements of resistance are expressed. It is defined as the resistance at a temperature of 0° centigrade of a column of pure mercury of uniform section, 106·3 centimetres long, and weighing 14·4521 grammes. This gives a section of 1 square millimetre.

A better idea of this resistance will be obtained by giving the dimensions of some wires offering 1 ohm resistance at the ordinary temperature of about 15° C. or 59° F.

1·55 feet of copper wire $\frac{1}{250}$th or ·004 of an inch in dia-

meter. This is the size of wire (No. 42 S.W.G.) much used for winding telephone receiver bobbins.

42 yards of a copper wire $\frac{1}{28}$th or ·036 of an inch in diameter. This is the wire (No. 20 S.W.G.) used for connecting up telephone instruments in offices.

71 feet of iron wire $\frac{1}{16}$th or ·0625 of an inch in diameter.

Very high resistances, such as the insulation resistances of line wires, are measured in *Megohms*—a megohm being equal to 1,000,000 ohms.

Ampere.—The strength of a current is measured in amperes —1 ampere being that current forced through a circuit of 1 ohm resistance by an E.M.F. of 1 volt. A current unit, termed the milliampere, is much used in telephony: it is equal to $\frac{1}{1000}$th of an ampere.

The Circuit.—The whole path through which an E.M.F. forces a current is called the *circuit*. It always forms a closed loop. When a current is flowing, the circuit is said to be *closed*, or *complete*. When the continuity of the conductors is broken by interposing an insulating body, the current ceases, and the circuit is said to be *open*, or *broken*. Some current, however, passes through substances of the highest resistance, so that the above statement only applies to the *useful* current.

Earth.—The circuit may be made up of different substances. In the majority of cases it is made up of wires, and other metallic parts; but even bad conductors, such as earth or water, may, when in large masses, form part of a useful circuit. For the sake of economy, the earth was in former days often used to complete the circuit for a telephone line, in order to save the expense of a second wire for a return connection. In present-day practice, however, double wires are almost invariably used for the speaking circuit; but for signalling purposes earth connections are often used in conjunction therewith. Lines consisting of "double" wires are termed metallic circuits. Such lines, if properly erected, are free from the serious defects peculiar to single or earth-circuit lines.

In making an earth connection, it is of the utmost importance that a conductor having a large surface in contact with

earth or water should be used as a medium of connection between the wire and the earth. For this purpose the water pipes of a town's water supply are generally chosen. If they are not available, iron or copper plates not less than 1 foot square are buried, preferably in damp ground, and the circuit wires connected to them.

Conductors in Series.—If, in a circuit, different conductors follow one after the other, these conductors are said to be joined up in *series*, as in Fig. 1. The resistance of a series circuit is the sum of the resistances of its several parts, including the

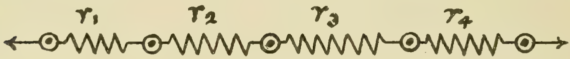


Fig. 1

resistance of the source of current itself. This may be expressed as $R = r_1 + r_2 + r_3$, etc.

Conductors in Parallel.—A circuit may be divided into several branches, which, however, must all meet again, as in Fig. 2. Such circuits are called *divided*, *parallel*, *branch*, or *shunt* circuits. The current flows through the different

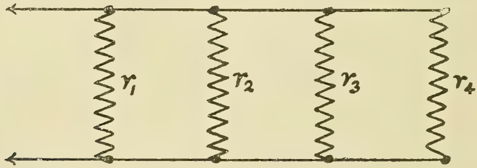


Fig. 2

branches of such circuits in direct proportion to their conductances, or in inverse proportion to their resistances.

Resistance of Divided Circuits.—The combined resistance of the several branches of a divided circuit between the two points where the circuit divides and the branches unite is equal to the reciprocal of the sum of the conductances of the several branches. In other words, it is equal to *the reciprocal*

of the sum of the reciprocals of the resistances of the branches, or $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$, etc. The reciprocal of a number is unity divided by that number. For example, the reciprocal of $20 = \frac{1}{20} = \cdot 05$, and the reciprocal of $\cdot 05 = \frac{1}{.05} = 20$.

If all branches of a divided circuit are of equal resistance, it follows that the combined resistance will be equal to the resistance of one branch divided by the number of branches. Thus if we had 20 branches, each of 40 ohms resistance, then $\frac{1}{R} = \frac{1}{40} \times 20 = \frac{20}{40}$, and $R = \frac{40}{20} = 2$ ohms. The combined resistance of two wires of 20 and 30 ohms respectively would be $\frac{1}{R} = \frac{1}{20} + \frac{1}{30} = \frac{30+20}{20 \times 30}$, or $R = \frac{20 \times 30}{30+20} = 12$, or expressed, decimally, $\frac{1}{R} = \cdot 05 + \cdot 033 = \cdot 083$ and $R = \frac{1}{\cdot 083} = 12$.

The above rules only apply when currents of practically unvarying strength are concerned. The resistance offered to fluctuating currents may be very different, as will be pointed out later.

Short Circuit.—A branch circuit which is of very low resistance as compared with the resistances of other working branches is termed a *short circuit*: it deprives the other branches of their working current.

Ohm's Law.—This is the most important of electrical laws, and may be stated as follows :—If the resistance of a circuit be expressed in ohms, and the total E.M.F. (or P.D.) in volts; then, if the E.M.F. be constant, by dividing the latter by the former the current flowing will be given in amperes. If R represents ohms, E volts, and C amperes, then the relation between the three will be represented by $C = \frac{E}{R}$, or $E = CR$, or $R = \frac{E}{C}$; so that, given any two of these quantities, it is easy to find the third. This law applies equally to a portion of a circuit as well as to the whole; so that if we know the P.D. between any two points of a closed circuit, and the strength

of the current passing, we can at once determine the resistance between the two points.

Medium of Propagation.—Whatever may be the real nature of the electric current which causes the effects produced, it is now generally admitted that the medium through which the cause of the current, or the energy of the current, is propagated, is not in the conductor itself, but in the insulating medium surrounding the conducting circuit. In other words, the energy absorbed and again given out by a generator of E.M.F. is transmitted through the ether surrounding the

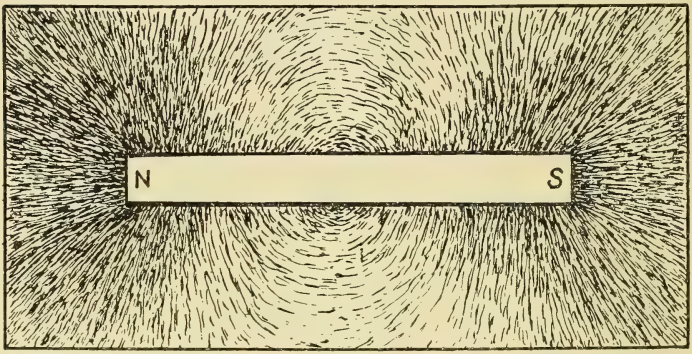


Fig. 3

conductor, and is from that *impressed* upon the conductor, so as to produce the various effects in the form of heat or work. The conductor merely acts as a guide to the electric waves, keeping them directed along the circuit instead of allowing them to spread in all directions through the ether (as happens in wireless telegraphy), and so become rapidly dissipated.

Magnetism.—*Magnetic Lines of Force.*—The reader will be familiar with the beautiful curves in which iron filings set themselves when sprinkled over a card covering a magnet, as shown in Fig. 3, where the magnet is shown above the card. At the poles, or points of greatest magnetic density, the lines are clustered together, and they spread out from these points

in symmetrical curves. These curves represent only sections of the *magnetic field* surrounding the magnet, and show the direction in which the magnetic force acts, and in which small magnetic needles free to move would set themselves. A piece of soft iron in the neighbourhood of the magnet modifies the magnetic field; and the curves are altered in shape, appearing to be concentrated by the iron, so that a greater number of the lines than formerly, pass through the space now occupied by the iron. In passing through the iron, the lines of force convert it into a magnet.

The conception of the idea of the existence of these so-called lines of force was due to Faraday, and the theory that such lines exist has proved of the greatest importance in electrical science. As actual lines they are just as purely imaginary as the lines of latitude and longitude on the earth's surface, and, like the latter, they have proved of the greatest service in enabling measurements and calculations to be made.

By arranging that the number of lines which, it is assumed, pass through a certain unit area in a magnetic field shall be in proportion to the intensity of the magnetic forces acting in that area, the forces exerted between magnets, and between magnets and currents, can be readily calculated.

The reader will, no doubt, be familiar with the simpler facts of magnetism: how pieces of iron or steel are attracted to the poles of a magnet; how, when small magnets are suspended at their centres so as to be free to move horizontally, one pole always points to the north and the other to the south, owing to the earth itself acting as a magnet; and how a magnet can impart magnetism permanently to pieces of steel by rubbing them with that magnet in a proper manner.

When soft iron is introduced into the field of a magnet, the iron is converted into a temporary magnet by the lines of force passing through it, but this magnetism disappears directly the magnet or iron is removed. Such magnetism is termed *induced* magnetism.

Like magnetic poles repel each other, and unlike poles attract.

The force of attraction or repulsion between poles is proportional to their strengths, and inversely proportional to the square of the distance between them. We cannot isolate one pole of a magnet from the other, so that in practice we always have both attraction and repulsion acting between the poles. These forces are expressed in terms of a unit called the *dyne*, which is a force such that, if it acted on a mass weighing 1 gramme (free to move) for 1 second, it would impart to that mass a velocity of 1 centimetre per second. A unit magnetic pole is one which exerts a force of 1 dyne on a similar pole at a distance of 1 centimetre in air. If m and m' represent the strengths of two magnetic poles, and d the distance between them, then $\frac{m \times m'}{d^2} = f$, the force in dynes of the attraction or repulsion between them in air.

Magnets.—The simplest form of magnet is the straight *bar magnet.* Magnets of *horse-shoe* pattern, Fig. 4, are, however, weight for weight, much stronger, the poles being closer, and the lines of force clustered together between them. They exert about three or four times the attractive power on a piece of soft iron near their poles that a bar magnet of the same size would exert. Fig. 5 shows the lines obtained when the card on which the filings are spread is laid on the ends of the poles N S.

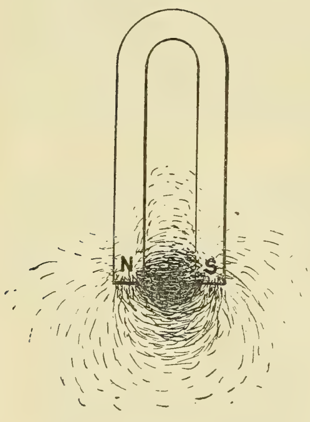


Fig. 4

Thin bars or plates of steel can be more powerfully magnetised, in proportion to their weight, than larger masses; therefore when a strong permanent magnet is required it is

generally made up of several thin plates, producing what is called a *compound* or *laminated* magnet. The plates are usually bound together by pieces of soft iron, which form the pole-pieces. Some compound magnets have been made which would carry a load equal to twenty-five times their own weight. The best cast steel, with an addition of 3 per cent. of *tungsten*, makes the best magnet steel—the value of which depends upon what is called its retentivity, or its resistance to change in its

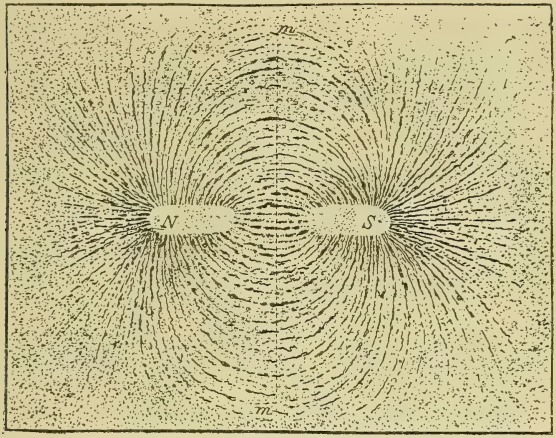


Fig. 5

magnetic state. This retentivity is the greater the harder the steel. By a process, however, of subjecting the steel to very great pressure, M. Clemandot has given a high retentivity to it, with the advantage that the metal can be filed, turned, etc., without impairing its magnetic value.

Magnetising.—The best method of magnetising is by means of a strong electro-magnet furnished with large pole-pieces. The steel is drawn over the poles, always in the same direction, some twenty or thirty times.

Small magnets, such as the needles of galvanometers, are liable to lose their magnetism from various causes—such as

lightning discharges or the proximity of strong currents. For such purposes it is much better to use soft iron needles polarised by means of comparatively large magnets fixed as near as possible to the needles.

Currents induced by Magnets.—Faraday's discovery that electric currents could be caused to flow through a coil of wire by the approach or recession of a magnet is of the greatest service in telephony (as in other branches of electrical science) Bell's original telephone being based upon it. These induced currents are only momentary, flowing only so long as the movement continues. They are in strength proportional to the strength of the magnet, the speed of its movement, and the number of turns of wire in the coil. The direction of the currents is dependent on which pole of the magnet is used, one producing opposite currents to the other. Also the currents produced by approach are opposite in direction to those produced by recession of the same pole.

Relative motion is all that is necessary, so that the same effects are produced by moving the coil to or from the magnet.

Faraday showed that, to produce these currents, it was necessary that the lines of force emanating from the magnet should be cut by the movement of the loops of wire, and he also showed that the strengths of the induced currents were proportional to the number of lines cut in a certain time.

Lenz's Law is applicable to all electrical induced effects, and states that "the induced currents have such a direction that their reaction tends to stop the motion or current which produces them."

Current Induction.—Wires conveying electric currents also exhibit magnetic properties, and are surrounded by a magnetic field and lines of force. A section of this field may be shown by passing a wire conveying a strong current vertically through a horizontal card and sprinkling iron filings over the card. The filings will arrange themselves in concentric circles round the wire, as in Fig. 6, which gives a plan of the card and section of the wire. Each particle of iron is in

reality made into a magnet by the lines of force passing through it. Freely-suspended magnetic needles would set themselves tangentially to the circles. The direction of the current in Fig. 6 is from above and down through the card. If it be conceived that a man were swimming *with* the current, and facing towards any one of the needles, the north pole of the needle would always be deflected towards the left hand of the swimmer.

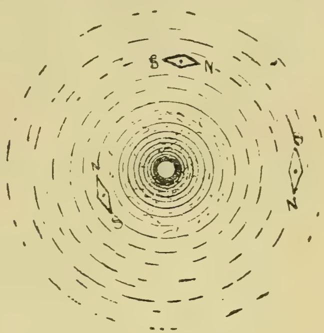


Fig. 6

When the wire is bent into a circle, a large number of these lines of force come together in the interior, as shown in Fig. 7, and the magnetic action there is consequently much more intense than in the case of a straight wire, and it is still further increased when the wire makes a number of turns to form a coil.

The *Electro-magnet* is constructed on this principle, the lines

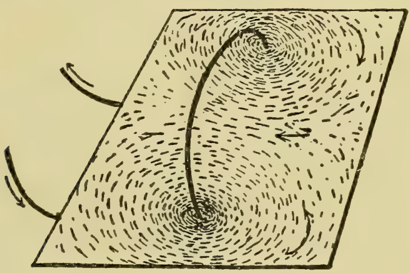


Fig. 7

of force passing through the soft iron core inside the coil or coils, rendering it powerfully magnetic. Fig. 8 gives a skeleton

diagram of a horseshoe electro-magnet, showing how the wire should be wound.

The Magnetic Circuit.—The conception and mathematical treatment of the magnetic field with regard to the strengths of the inducing forces, and the resulting magnetic forces or *fluxes*, have been, within the last few years, considerably modified. It is now treated in a manner more in consonance with that of Ohm's law as applied to the electric circuit. The magnetic law is expressed by the formula $\Phi = \frac{\mathscr{F}}{\mathscr{R}}$, where the Greek letter Φ represents the total magnetic induction or *flux* produced, measured in units called the *maxwell.* The script letter $\mathscr{F}$ represents the *magneto-motive force* measured in *gilberts*—this force being the inducing force, which in the case of electro-magnets is proportional to the strength of the current multiplied by the number of turns the wire makes round the core, this product giving the *ampere-turns.* One gilbert = 1·257 ampere-turns. $\mathscr{R}$ represents the magnetic *reluctance* or resistance to the flow of the magnetic flux through the several parts of the magnetic circuit, measured in *oersteds.* The oersted is the reluctance of 1 cubic centimetre of vacuum. As in the case of electric resistance, reluctance varies in different substances, and is directly proportional to the length and inversely proportional to the cross section of the substance in question. Non-magnetic substances all have about the same reluctance as a vacuum. Any two of the quantities in the formula being known, the other is easily calculated.

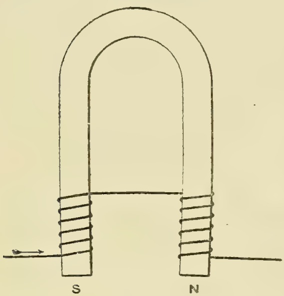


Fig. 8

So far this exactly corresponds with Ohm's law as applied to currents; but an important difference is found in the fact

that, whilst the resistance in an electric circuit remains constant (whatever may be the E.M.F. and current) if other conditions remain constant, the reluctance of magnetic materials, especially iron and steel, varies very considerably with the different intensities of $\mathcal{H}$ to which they are subjected. This is shown by Fig. 9, which gives curves showing how the magnetic flux through certain pieces of iron and steel increases as the inducing force is increased. Distances measured horizontally from the vertical line O Y represent

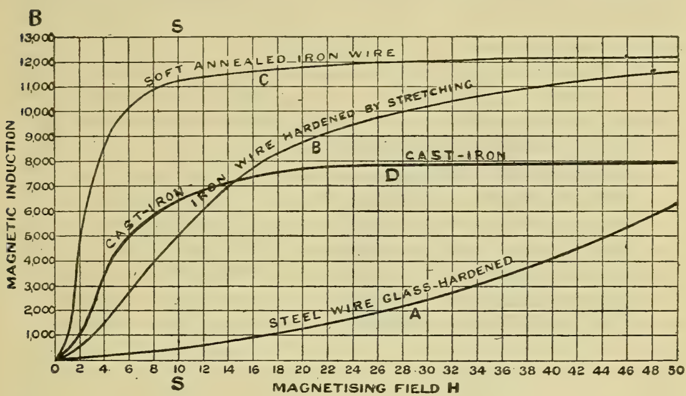


Fig. 9

the *intensity* of the magnetic field or the number of gilberts per square centimetre, this intensity being represented by H. Distances measured vertically from the horizontal line O X represent the *intensity* of magnetism or the magnetic flux per square centimetre, which is represented by B.

Permeability.—When the value of B at any point of either of the curves is divided by the corresponding value of H, we obtain the magnetic conductivity of the material at that point. This quality is called its *permeability*, and is designated by the Greek letter μ. It is the converse or reciprocal of the reluctivity of the material.

On the line SS it will be seen that $H = 10$; B for soft iron

is 11,200, for cast iron 6,500, for stretched iron wire 5000, and for hard steel about 450. These figures give the permeability as $\frac{11,200}{10} = 1,120$; 650, 500, and 45 respectively.

It will be seen that at the line *SS* the soft iron and cast iron are approaching *saturation* point when an increase of *H* does not produce any increase of *B*.

Practical Points regarding Electro-magnets.—Small electro-magnets are usually constructed by fixing on the soft iron core or cores of the magnet one or more bobbins wound with silk-covered copper wire. Fig. 10 shows a common horseshoe form, as used in electric bells, relays, etc. The inside ends of the wires are brought out through holes in the ends of the bobbins, and these ends are usually soldered together, leaving the two outside ends to form the terminals of the connected coils.

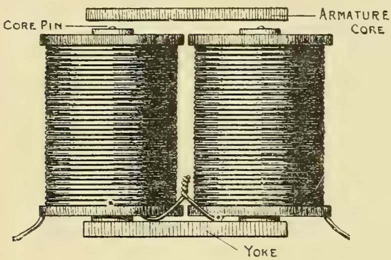


Fig. 10

To obtain the best results, the cores, armature yoke, and other iron components forming parts of the magnetic circuit, should be made of the softest iron, which is usually Swedish, well annealed *after* the necessary turning and filing have been finished, as these operations reduce the permeability of the iron, rendering it hard, and liable to retain magnetism after the inducing current has ceased. To avoid the last-mentioned trouble, it is also necessary to prevent the armature making actual contact with the iron cores, because if the magnetic circuit is, as it were, short-circuited in this manner the magnetic flux, termed residual magnetism, is liable to persist after the current is broken, and so overcome the desired tendency of the armature to return to the normal position. To prevent this effect, it is usual to drill small holes in the ends of the cores,

in which are inserted *core-pins* of brass wire, projecting very slightly from the ends of the cores.

When an electro-magnet has to be used in a circuit of high resistance, the number of turns of wire on the coils should be large, in order that the total magnetic effect (proportional to the number of turns) of the feeble current may be great enough to exert on the armature or needle sufficient force to produce the desired movement. This entails the use of thin wire for winding the coils. In winding a magnet intended for use in a circuit of low resistance it is best to use thick wire, but the number of turns should be as large as the bobbin will allow.

The wire in the coils of a horseshoe magnet must be connected up so that the windings would be continuous in one direction if the magnet were straightened out. This is shown in Fig. 8. In practice this object is attained by joining the two inner ends of the wires together, as in Fig. 10. In the ordinary *Galvanometer* a small magnetic needle takes the place of the core of the electro-magnet. The needle is so pivoted inside the coil that by the force of gravity in the case of vertical dials, and by the earth's magnetic action, or the action of a permanent directing magnet in the case of horizontal dials, the needle tends to set so that its axis is in the same plane as, or a plane parallel to, that of the turns of the wire on the coils. When a current passes through the coils its magnetic action tends to turn the needle at right angles, or along the axis of the coils.

The galvanometer used in telephonic work, for roughly testing batteries, tracing faults, etc., is called a *detector* galvanometer. Fig. 11 shows the interior of a common form, having one of the bobbins, or frames on which the coils are wound, removed so as to show the pivoted magnetic needle N S. The index needle or pointer P, shown in dotted lines, is fixed to the same pivot at the front of the dial plate. When the other bobbin is in position the needle is completely enveloped, but is free to move inside. The magnetic field produced by a current passing through the coils tends to set the needle

horizontally. This force is opposed by gravity, the lower half of the needle's length being made heavier than the upper half, so that the sensitiveness of the instrument will depend to a great extent upon the difference in weight between these two halves of the needle.

The instrument is generally furnished with two coils of wire on each bobbin. One winding, consisting of a few turns of thick wire, is used when roughly measuring low resistances,

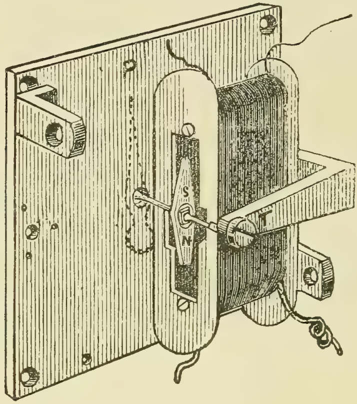


Fig. 11

such as the internal resistance of a battery. The other winding has a large number of turns of thin wire, having a resistance of about 150 ohms. This winding is used when testing circuits of high resistance, and for roughly measuring the E.M.F. of cells.

For important measurements, recourse must be had to more accurate and reliable instruments, such as ammeters and voltmeters (which are properly calibrated, and so give correct readings of the current or voltage), or to some form of reflecting galvanometer such as is described in the chapter on Electrical Measurements.

The *Induction Coil*, in its most common form, may be looked

upon as consisting of an electro-magnet of low resistance, having another coil wound over the first. This latter coil is usually made up of a large number of turns of fine wire. Whenever the current in the *electro-magnet* or *primary* coil of wire is started or stopped, or its strength varied, induced currents are produced in the other or *secondary* coil, providing the circuit of the latter be complete. The starting or strengthening of a current has the same effect as bringing up a magnet to the coil, and the stopping or weakening the same effect as taking away the magnet from the coil. The strengths of the induced currents depend upon the number of turns of wire on both coils, and the rate of variation in the strength of the magnetising or primary current. The current induced on starting or strengthening the primary current flows in a direction opposite to that of the latter, while the current induced on stopping or weakening the primary current is in the same direction as the latter. The cores of induction coils are usually made up of a bundle of thin iron wires, in order to reduce the reactive effect on the primary current, and because it has been found that such cores gain and lose magnetism more quickly than solid ones, and a greater rate of variation in the magnetism can, therefore, be obtained.

The reaction of the induced currents on the primary currents opposes, and so weakens, the latter, according to Lenz's law.

Repeaters or Translators.—These are induction coils in which the coils are of equal, or nearly equal, resistance and number of turns. They are used for connecting one telephone line with another so that speaking and ringing can take place, but without direct metallic connection between the two lines, one line being connected to one coil and the other line to the second coil.

Inductive Effects on Straight Wires.—Owing to its magnetic action, a current passing through a straight wire will induce currents in another wire running alongside when the current is varied in strength. The strengths of the induced currents depend upon the rate of the variations of the inducing currents,

the distance between the wires, and the distance for which they run together. These inductive effects are due to the *magnetic* action of the current; but there are other induced currents, produced in parallel wires by changes in the *statical* charges when the primary current is varied. These will be referred to later.

In explanation of the cause of induced magnetic effects, it may be conceived that, when a current is started in a wire, the circular magnetic lines of force (referred to on page 12) spread out from the wire through the ether, like sound waves in air, or like the waves on the surface of water when a stone is dropped in, but at an inconceivably greater velocity. If these etheric waves encounter, or are cut through by, any conductor, an E.M.F. is set up in that conductor, tending to produce a current. On the stoppage or weakening of the original current the etheric waves reverse their direction, and converge on the conductor carrying the current, producing in it, and in any other conductor which cuts through the converging lines of force, an E.M.F. opposed to the first induced E.M.F., and thus tending to send a current in the same direction as the primary current.

Self-Induction.—Any wire conveying a current may be looked upon as made up of a number of smaller wires laid side by side, each conveying a portion of the full current. Each of these small currents will have a magnetic field of its own, which acts inductively on the other portions of the whole wire, and opposes the variations of strength of the main current. If the wire is in the form of an ordinary coil of many turns, then the self-inductive action is greatly increased, owing to the magnetic field due to any one turn of the coil acting upon every other turn of the coil, just as though each of these turns constituted a separate coil. The result of the magnetic field around each turn of a coil acting in this way on every other turn is to produce a momentary reverse E.M.F. in the coil, tending to send a current in an opposite direction, and so retard the starting of the originating current. On breaking the circuit, the effect is to produce an assisting E.M.F. (which may be much stronger than the original E.M.F.), having the effect

of carrying on the current after the circuit is broken. The evidence of this latter effect is seen in the vivid spark obtained at the point of breakage when a circuit which includes an electro-magnet, and through which a current is flowing, is broken. The whole effect of self-induction, or *inductance*, is to impart inertia to the current, which, like the inertia of material bodies, opposes the setting in motion of, or acceleration of electricity, and also opposes the retardation or stoppage of its motion. One of the results of this is that inductance, if evenly distributed along a circuit, enables a current wave to travel farther, or with less loss of strength, than if that quality were absent.

The addition of a soft iron core to a coil adds greatly to its self-induction, so that an electro-magnet possesses inductance to a high degree, and offers great obstruction, or *impedance*, to rapidly-varying currents such as those concerned in telephonic transmission of speech. The more iron there is used in the construction of an electro-magnet in closing the magnetic circuit the less the magnetic reluctance and the more marked the impedance.

Inductance is measured in terms of a unit called the "henry," which is the inductive effect producing an E.M.F. of 1 volt when the inducing current varies at the rate of 1 ampere per second. Inductance in "henries" is represented by the symbol "L."

Inductive Capacity.—That quality of an insulating medium which determines the intensity of statical induction between conductors is termed its *inductive capacity*. The statical inductive effects between wires vary according to the medium intervening. When dry air separates the wires, the inductive effects are less than under any other conditions. If the *inductive capacity* of air be taken as unity, that of resin is 1·7, paraffin 2, india-rubber (raw) 2, india-rubber (vulcanised) 2·5, manilla paper 1·8 to 2·5, ebonite 2·3, glass 3·3, mica 5, gutta-percha 2·5. It is important to consider these values in connection with cables for telephone wires, and, if possible, to choose as an insulating medium a substance which has the

least inductive capacity, for, as will be seen later, statical induction has a very detrimental effect on telephonic currents or waves. For these reasons the most successful cables used in telephony depend principally upon dry air for the insulation of their wires.

Statical Capacity Effects.—Every current passing through a wire charges every part of it with statical electricity, to a certain potential, the charge depending upon the voltage of the current, the surface area of the wire, the proximity of other conductors, and the specific inductive capacity of the materials intervening between the conductors. This charging weakens the original current by abstraction of electricity, and it weakens succeeding currents by opposing their growth. The action in question is very marked in the case of cables, where the wires are close together, and more especially when very rapid variations of potential are concerned. It is on account of this action that telephonic speaking through more than a few miles of cable wire is, under ordinary circumstances, impracticable. We shall see, however, in a later chapter how the difficulty has, to a large extent, been overcome, and how the impedance or reactance due to inductance has been used to neutralise the impedance due to inductive capacity. On overhead lines the capacity effect is comparatively small, as the conductors are wide apart, and are separated by air, which has the least inductive capacity.

Microfarad.—The unit of capacity has been named the *farad*, but as this is much too large for practical use, a sub-unit called the *microfarad*, which is one-millionth part of a farad, is used. About 12·5 miles of No. 20 S.W.G. wire in a dry-core cable has a capacity of about 1 microfarad. Capacity in *farads* is represented by the letter K.

Condensers.—In order to compare the inductive capacity of cable wires, *condensers* are employed, the object of the condenser being to obtain a large capacity in a small space by using conductors of large superficial area, brought very close together without touching. Condensers are made with a large number of sheets of tinfoil laid face to face,* but each one

* See page 579 for Mansbridge Condensers.

is completely separated from that adjoining by an insulator, such as a sheet of thin mica or waxed paper. Commencing from one end, alternate sheets are connected together in some convenient manner, and soldered to a terminal, and all those intervening are also connected together, and to a second terminal.

When one of these terminals is connected to some source of electricity, so that its potential is raised, whilst the other terminal is connected to earth or some source of opposite potential, there will be, or appears to be, an accumulation of electricity on the surfaces of the two sets of tinfoil sheets. If the two terminals are now connected together, the accumulated charges combine, and a discharge takes place, in the form of a strong current, causing sparking, etc. If, whilst charged, the potential of the first terminal be lowered, the charges on both sets are partly set free, and produce momentary currents. As long as the potential at the terminals is varying, currents are passing to and fro from both sets of tinfoil sheets. It will thus be seen that magneto-electric ringing currents may be readily transmitted through a condenser. Still more readily may more rapidly alternating currents, such as telephonic speaking currents, be transmitted, because the more rapid the alternations the more efficient the condenser. The effect produced is just as though the currents passed directly through the sheets which insulate the tinfoil plates.

Reactance is the measure of the resistance which the inductance, or capacity, or both, in or of a conductor offers to the setting up of a variable current flowing through it, apart from the ordinary ohmic resistance as offered to the flow of a steady current. It may be measured as a resistance in ohms, and is proportional to the inductance or capacity, or both, of the conductor, and the *rate* at which the urging or *impressed* E.M.F. is varying per second. If n represents the number of current waves per second, then the reactance due to inductance alone is $2\pi n\text{L}$, that due to capacity alone is $\frac{1}{2\pi n\text{K}}$, and that due to both $= 2\pi n\text{L} - \frac{1}{2\pi n\text{K}}$.

Impedance is the total resistance which is opposed to the setting up of a variable current in a circuit. It is made up of the ordinary resistance for steady currents (sometimes called the ohmic resistance) and the reactance of the circuit as given above, but not quite as the sum of the two, but as the square root of the sum of the squares. For example: for inductance with resistance the formula is, impedance $= \sqrt{R^2 + 4\pi^2 n^2 L^2}$; for capacity and resistance $= \sqrt{R^2 + \frac{1}{\sqrt{4\pi^2 n^2 K^2}}}$; and for all combined it $=$

$$\sqrt{R^2 + \left(2\pi n L - \frac{1}{2\pi n K}\right)^2}$$

Although not clear at first sight, it is possible for the $\frac{1}{2\pi n K}$ factor to equal, or greatly exceed, the $2\pi n L$ factor, as, the K being measured in *farads*, the capacity of the longest line or cable is only a very small fraction, and, therefore, the reciprocal may be a large whole number.

Wire Gauges.—Wires were formerly compared in size by the Birmingham wire gauge, but its unreliability—from the fact that several different gauges existed, all professing to be the B.W.G.—led to the British Board of Trade issuing what is called the *British Imperial Standard Wire Gauge*, a list of the most useful sizes of which is given at the end of the book.

The Brown & Sharp (B. & S.) wire gauge is used in America for copper wire, and has the advantage of being based on a definite principle instead of being purely arbitrary, as is our S.W.G. The principle is that the sectional area of any gauge, multiplied by $\sqrt[3]{2}$ (the cube root of 2 = about 1·26), gives the sectional area of the next size larger, and, divided by the same number, gives the sectional area of the next size below. In this way the wires double in sectional area at every third gauge.

The Mil.—A better way of comparing wires is to give their diameter in thousandths of an inch, which are termed *mils*.

This mil must not be confounded with the French millimetre, which is equal to 39·37 mils. A micrometer gauge is used to measure mils, and a very convenient one for the purpose is shown full size in Fig. 12. It is worked by a fine screw, and easily measures to half-a-mil.

Poole's Electrician's Wire Gauge.—The two sides of this gauge, which was invented by the writer, are shown in Figs. 13 and 14. By the simple process of inserting a copper wire in the slots shown, and moving the wire round until it is stopped, the instrument will furnish nine different readings in regard to the electrical properties, etc., of the wire, and by making use of the table of resistivities given on page 3 the same particulars may be obtained regarding wires of other metals. By the peculiar shape of its recesses, this instrument has the

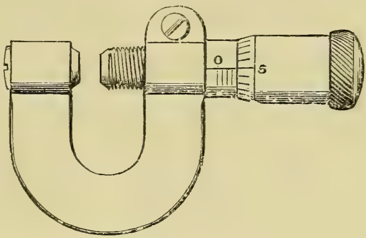


Fig. 12.—Full size

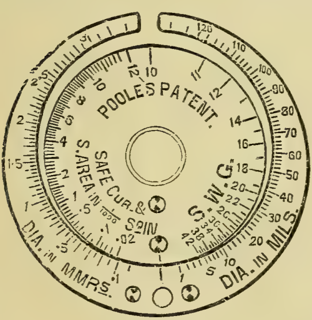


Fig. 13

Scale $\frac{2}{3}$

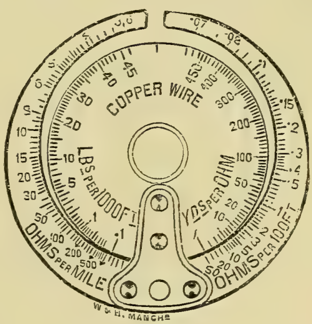


Fig. 14

advantage over the ordinary straight V-shaped gauge of giving a much larger practicable range within smaller dimensions.

Copper Wire.—The following are very useful formulæ for the calculation of resistance, etc., of *pure* copper wires, the diameters being given in mils :—

1. The resistance per mile of a wire d mils in diameter $= \frac{54505 \cdot 4}{d^2}$ legal ohms.

2. The weight per mile $= \frac{d^2}{62 \cdot 57}$ lbs.

3. The diameter of a wire weighing n lbs. per mile $= \sqrt{n} \times 7 \cdot 91$ mils.

4. From (1) the resistance of a wire 1 foot long and 1 mil diameter $= 10 \cdot 2$ ohms ; from which is obtained :

5. The resistance of a wire l feet in length and d mils in diameter $= \frac{10 \cdot 2 \times l}{d^2}$ legal ohms.

If the wire is of any other metal than copper, its resistance may be obtained by multiplying the resistance obtained for a copper wire of equal size (by No. 1 or No. 4 formula) by the number giving the comparative resistance of the metal on page 3.

The above formulæ only hold good for wire at a temperature of 60° F. or 15° C., but are sufficiently accurate for rough purposes.

Temperature Effect.—If more accuracy be required, account must be taken of the fact that the resistance of copper increases at the rate of ·23 per cent. for each degree Fahrenheit increase of temperature, or ·42 per cent. for each degree Centigrade. If R is the resistance at a certain temperature, and R_n is that at n degrees higher, then $R_n = R + (R \times \cdot 0023n)$ very nearly. If the temperature is decreased n°, $R_n = R - (R \times \cdot 0023n)$.

When the Centigrade scale is used, ·0042 must be substituted for ·0023.

Most of the commoner pure metals have a *temperature coefficient* about equal to that of copper, but some of the alloys, such as German silver, platinoid, and manganin, have a much lower coefficient, that for platinoid being only about 0·011 per cent., whilst that of manganin is only about 0·0025

per cent. These alloys, having also a high resistivity, are, therefore, used for the resistance coils employed in measuring resistances.

Ohm-mile.—A convenient way of designating the size of uncovered wire is by its weight per mile. This method is adopted to a large extent in the telegraph and telephone service. On multiplying the weight of 1 mile of wire of a certain material by its resistance a number is obtained which is constant for that material, and is known as the *Ohm-mile*, as it represents the weight of 1 mile of a wire of that material measuring 1 ohm resistance. The resistance of a mile of any other wire of the same material can be at once found by dividing the constant by its weight per mile, or its weight per mile is obtained by dividing by its resistance per mile.

The constant for the hard-drawn copper wire used for telephone lines is 892, or, roughly, 890. That for the silicium bronze wire generally used for telephone lines may be taken at 1800.

The *Percentage Conductivity* of any wire is the conductivity of that wire compared with that of a pure copper wire of the same dimensions, at the same temperature, the conductivity of the pure copper wire being taken as 100. It is obtained by multiplying the calculated resistance of the pure copper wire by 100, and dividing the product by the actual measured resistance of the wire in question.

CHAPTER II

BATTERIES

(1) *Primary*

NOTWITHSTANDING the many sources of E.M.F. and current available, it has so far always been found necessary to employ some form of galvanic battery in telephone work, so that a few facts relative to the forms in common use will be desirable.

Simple Galvanic Cell.—When two electrical conductors are dipped into a conducting solution in which the conductors are acted upon chemically to a different degree, an E.M.F. is set up, and each of the conductors becomes slightly charged with electricity—one positively and the other negatively. If next the conductors be joined by a wire or other conductor, this will give evidence that an electric current is passing through it, and certain chemical actions will take place between the solutions and the conductors—some constituent of the solution being split up into simpler chemical substances, one of which enters into combination with the conductor most acted upon, while the other is generally liberated at the second conductor. For example, if plates of zinc and carbon are dipped into a dilute solution of sulphuric acid, and then joined by a wire, as in Fig. 15, the sulphuric acid, of which the chemical symbol is H_2SO_4, is gradually split up, the SO_4 part entering into combination with the zinc plate to form zinc sulphate ($Zn\ SO_4$) and the hydrogen being liberated at the carbon plate in the form of gas. The wire joining the plates will give all the evidences of the passage of an electric current. The plate most acted upon (which is generally

zinc) is called the *electro-positive plate* or *element*, and the other plate the *electro-negative element*. The current passes from the zinc through the liquid, which is called the *electrolyte*, to the carbon, then from the carbon through the wire to the zinc plate. The point at which the wire makes connection with the carbon plate is termed the *positive pole*, and that point at which connection is made to the zinc is termed the *negative pole*.

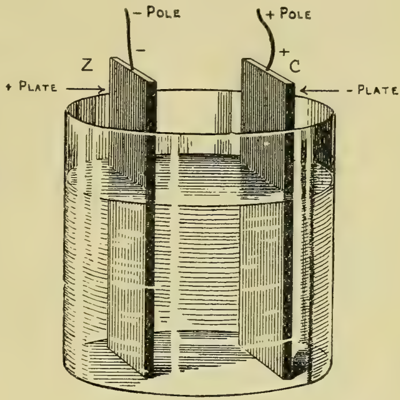


Fig. 15

The amount of chemical action which goes on, providing the plates are of pure materials, is in exact proportion to the strength of the current which passes, so that if it is known how much zinc is dissolved, or how much hydrogen gas liberated, in a certain time, it is easy to calculate what strength of current is generated, or, if the strength of current be known, the zinc dissolved and hydrogen liberated may be calculated.

Polarisation.—The deposition of gas, usually hydrogen, on the electro-negative element gives rise to an opposing force in the circuit, as it adheres to the plate, and increases the resistance in the path of the current. This gas is further instrumental in giving rise to opposition to the original current, by taking part in the production of an E.M.F., which tends to send another current in the opposite direction, so that the E.M.F. of the cell falls, and the current is weakened while the gas remains on the plate. The different forms of cells in use represent so many methods of preventing this *polarisation*, generally by introducing some substance which will enter

into chemical combination with the gas, and thus prevent its deposition.

Local Action.—As before stated, the metals (generally zinc), used in galvanic cells should be pure, as if they are not, chemical action will go on even though the plates are not electrically connected, and the metals will be used up unprofitably. This is caused by the impure parts, of, say, a zinc plate, being electro-negative to the pure parts. Very small galvanic circuits result, and the zinc is dissolved and wasted.

Amalgamating.—As pure zinc is too expensive for commercial use, the surface of zinc plates or rods is covered with a thin coating of an amalgam by rubbing over with mercury. This presents a uniform surface to the electrolyte, and thus prevents local action. In working, the amalgam parts only with its zinc, and the mercury enters into combination with a fresh portion of zinc.

Qualities of Cells.—The qualities which it is desirable a cell should possess may be summed up as follows :—

1. It should have a large E.M.F.
2. This should remain constant in working.
3. Its internal resistance should be small.
4. This latter should be constant.
5. The materials it consumes should be cheap.
6. There should be no waste of such materials when the cell is not in use—that is, no *local action* should take place.
7. Its condition should be capable of being easily inspected.
8. It should be easily refreshed or replaced.
9. It should not emit offensive fumes.
10. Its first cost should be small.

No one cell is known which unites in itself all the above qualities ; each cell has its special advantages ; so it becomes a practical question to decide which are the most important conditions necessary for any particular purpose.

For ordinary telephone work the most important qualities are Nos. 5, 6, and 9, but Nos. 1, 7, 8, and 10 are also of importance. No cell has yet been found which unites these qualities so well as the Leclanché in its various forms. Its

great fault is that it is deficient in constancy when heavily worked.

The Leclanché Cell.—The ordinary form is made up of a glass vessel of the shape shown in Fig. 16. Into this a zinc rod, provided with a connecting wire, is placed. Inside the glass vessel is a cylindrical pot of porous earthenware containing a carbon plate, round which is packed a mixture of about equal parts of carbon and needle binoxide of manganese broken into pieces of about the size of peas, care being taken to exclude dust. The carbon plate is provided with a lead cap and terminal.

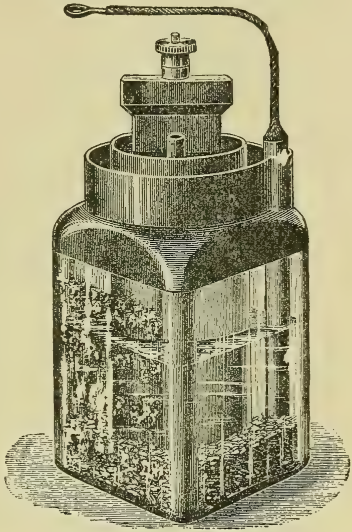


Fig. 16

To set in action, the glass is nearly filled with a saturated solution of sal-ammoniac or chloride of ammonium. This gradually percolates through the porous pot, until the whole is left about three-fourths full of liquid.

The action which takes place, under favourable conditions, is as follows :—The zinc combines with the chlorine of the sal-ammoniac to form zinc chloride, which is dissolved in the solution, whilst the hydrogen set free from the sal-ammoniac robs the binoxide of manganese of some of its oxygen to form water —ammonia being also given off, as shown in the chemical formula : $Zn + 2NH_4Cl + 2MnO_2 = ZnCl_2 + H_2O + 2NH_3 + Mn_2O_3$.

If the cell is hard worked, the action becomes more complicated, substances, such as oxy-chlorides of zinc, being formed which are with difficulty dissolved by the solution,

and soon impair the working, and lead to the polarisation of the cell. On allowing it to rest, however, its power is quickly regained.

One of the best features of the Leclanché cell is that no *local action* or waste of materials takes place when not in use, unless impure zinc is used. The ammonia gas given off during action is not offensive, and is seldom noticed, unless the cell is very hard worked.

There are many practical points in connection with the cell to which attention should be paid.

Carbon Plate.—The attachment of the lead cap to the carbon is one of the most important points, and much trouble was at one time experienced by the solution creeping up through the pores of the carbon, and acting upon the lead and the terminal. This quickly corroded, and destroyed the connection. To prevent this action, about 2 inches of the top of the carbon should be soaked for some time in hot paraffin wax. This plugs up the pores, so that the creeping cannot take place. To ensure a good connection between the terminal and the carbon, the latter should have two or three holes of about $\frac{1}{4}$ diameter drilled at about $\frac{3}{16}$ of an inch from its top edge, and the shank of the terminal should be tinned before the lead is cast round it and the head of the carbon.

The terminals, if made of brass, are apt to be corroded by the ammonia fumes, and by solution dropped on them accidentally. No such corrosion takes place if the terminals are made of Britannia metal.

The top of the porous pot should also be soaked in paraffin, and the carbon block and mixture kept in place by a covering of marine glue about $\frac{1}{4}$ inch thick, in which two small ventilating holes are made. The holes are useful also for pouring a little of the solution into the pot when the cell is required to work at once.

The porous pots should be rather soft, as hard pots offer too great a resistance, and so prevent the cell giving sufficient current for a transmitter. Such pots, however, will do for a ringing battery.

Only the best needle manganese should be used, or the cells will soon give out. It is desirable, therefore, to obtain the cells from the best makers, who only use first-class materials. The same applies to the sal-ammoniac used, as impurities in it give rise to local action.

The zinc rod is best made of rolled metal, and care should be taken that its wire connection is well soldered.

The glass cell should be coated at the top for a distance of about 2 inches, inside and out, with black Japan varnish, to prevent the solution from creeping over the edge of the jar and down the outside by capillary action. The cell is often drained dry in this way, to the detriment of wall-paper, etc., in the offices where it is fixed. The solution will not wet the varnish, and so creeping is prevented. Paraffin wax is sometimes used for the purpose, but is not nearly so effective. The lead cap and top of carbon should also be varnished.

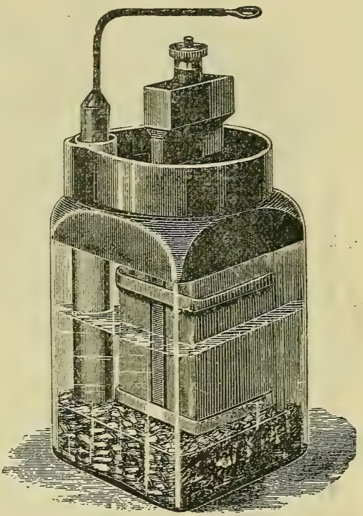


Fig. 17

The cells are made in three sizes. The No. 2, or medium, is the one mostly used; but the No. 1, or largest size, is frequently employed for the working of transmitters with much advantage, as they are heavily worked, and a greater body of depolarising material is desirable, and more solution to keep up its strength. A stronger current is also obtained, as the internal resistance is only about 1 to 2 ohms, while that of the No. 2 is from 2 to 4 ohms.

The E.M.F. of the Leclanché = 1·46 volts at starting.

The Agglomerate Leclanché.—In order to get rid of the

porous pot and its resistance, a mixture of carbon and binoxide of manganese is solidified by being crushed and mixed with a proportion of gum-lac resin. The resulting compound is put into moulds, and subjected to a great pressure, after being heated to 212° F. The solid blocks thus formed are fastened round the carbon-plate by india-rubber bands, usually provided with small holes for the zinc rods, to keep the latter from touching the blocks. For the same purpose, and also to prevent the cell running down too quickly, small porous pots are sometimes provided for the zincs, as shown in Fig. 17.

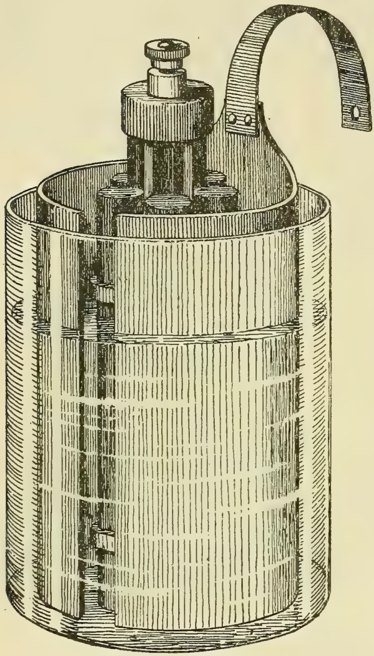


Fig. 18

Fig. 18 shows a later form, called the *six-block agglomerate* cell. A fluted carbon block is used, to which are bound six cylindrical agglomerate blocks, completely protecting the carbon from direct action. With it may be used a cylindrical zinc surrounding the blocks, thus very materially reducing the internal resistance of the cell, which is usually less than 0·5 ohm.

The expectation that these agglomerate cells would altogether supplant the porous pot form has not been realised, as they have not proved so reliable. They are, however, used in preference to the latter when specially strong currents are required.

DRY CELLS.—Within the last few years various forms of what are known as *dry cells* have come extensively into use. Those mostly used for telephonic purposes, such as the "Hellesen," the "E.C.C.," the "Obach," the "Delafon," etc., are all modifications of the Leclanché cell, inasmuch as the same elements, zinc and carbon; the same depolariser, manganese dioxide; and the same excitant, a solution of sal-ammoniac, are used. The term "solution" will seem strange in connection with a "dry" cell; but this term is a misnomer, as no perfectly dry cell would give current. It is so called because it gives no outward evidence of containing a liquid.

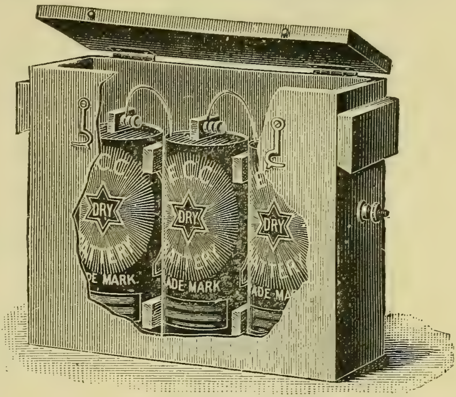


Fig. 19

Fig. 19 gives a view of three E.C.C. dry cells in a box, and Fig. 20 a section of one of these cells. This has been a very successful form of dry cell, and a very large number have been used by the National Telephone Company and other firms. The carbon plate, C, is surrounded by a black paste, the composition of 100 parts of which is approximately as follows:—carbon 37, manganese dioxide 23, silicious dioxide 11, magnesium oxide 7, water 10, and 12 parts of other non-important materials. This paste occupies most of the cell, and is separated by canvas, or other porous material, from a white paste, S, made up of calcium oxide, with organic matter 20 parts, the other 80 parts being made up of a saturated solution of sal-ammoniac. This white paste is in contact with a cylinder of zinc, Z, which forms the electro-positive plate. A cardboard cylinder, O, covers and protects the

whole except the top. The two pastes are covered by a disc of paper, then a layer of cotton wool, W, and finally sealed by bitumen, P, through which a ventilating tube is passed to allow of the generated gases escaping. The chemical action which takes place when in use is similar to that of the ordinary Leclanché, and the cell becomes exhausted when the solution of sal-ammoniac is used up.

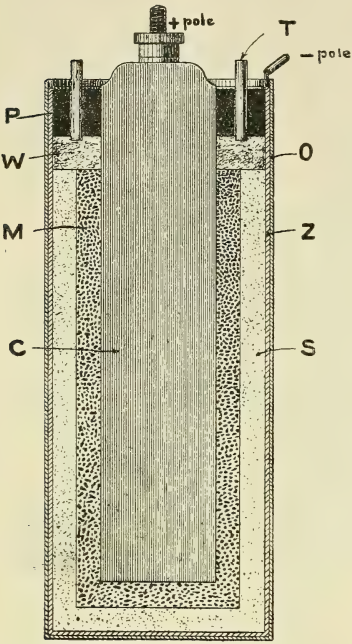


Fig. 20

Most of the other forms of dry cell are similar to this, differing only in details of the various pastes used. The internal resistance of these cells is much lower than that of the wet form of Leclanché, being when new only about ·1 of an ohm; the cells will, therefore, give a powerful current through a small external resistance. The E.M.F. is about 1·4 volts per cell at first but rapidly falls when in action. Dry cells should be kept in a cool place, or they will become *actually dry*, and will fail to give current.

The Delafon Cell.—This is a successful cell made in both a wet and dry form. The special feature appears to be an agglomerate mixture which instead of being mixed with some binding ingredient and then solidified by heat and pressure is merely subjected to great pressure to effect solidification. Blocks of this are bound to the carbon plate by wrappings of cord and canvas. In the dry cell the immobility of the liquid

electrolyte is obtained by a special preparation having fecula as a basis.

Mr W. R. Cooper, in his work on Primary Batteries, gives the results of a comparison of tests of a number of different forms of Leclanché cells, including "dry" forms, and the following particulars of the behaviour of different forms of cells when worked continuously through an external resistance of 10 ohms has been mostly based on his table with the addition of particulars in regard to the Delafon dry and wet cells.

	Relative Efficiency	Useful Life in days	Weight lb.	oz.	Capacity in days per lb.
E.C.C. Dry Cell .	21·5	8·1	2	6	3·41
Hellesen . . .	21	10	3	1	3·26
Obach . . .	20	7·7	2	4	3·42
Six - Block Leclanché	10	15·4	9	8	1·52
Porous Pot ,,	6	7	7	8	·93
Agglomerate Block ,,	4	4·2	6	12	·58
Delafon, Dry . .	44	20	2	14	6·96
,, Wet . .	18	22	7	14	2·83

The Daniell Cell.—In the matter of constancy, the Daniell cell is superior to all others when a long-continued supply of current is required.

The ordinary Daniell cell is made up of a copper plate or cylinder immersed in a saturated solution of sulphate of copper, which is separated by porous earthenware from a vessel containing a zinc plate or cylinder immersed in a weak solution of sulphate of zinc. The hydrogen, instead of polarising the cell, acts upon the sulphate of copper, and metallic copper from this is deposited on the copper plate.

The defects of the Daniell are that its internal resistance is high, and that the fluids get mixed, through the division. Much local action results, and if the cell be disconnected it will not recuperate. Its E.M.F. is also low, being only 1·065 volt.

To remedy these defects to some extent, advantage has been taken of the fact that the specific gravity of a saturated solution of sulphate of copper is greater than that of a weak solution of sulphate of zinc, to form what are called *Gravity*

Cells. In these the copper element, made up of riveted strips, is fitted at the bottom of a glass jar, connection being made by an insulated copper wire passing through the liquid. The jar is filled three parts full with a saturated solution of sulphate of copper, to which extra crystals are added. Over this a weak solution of sulphate of zinc is very carefully poured so as not to mix. In the zinc solution a "crowfoot" shaped zinc is hung over the edge of the jar as shown in Fig. 21.

Much attention must be paid to these cells, for if the solution of sulphate of zinc gets too strong, it becomes heavier than the

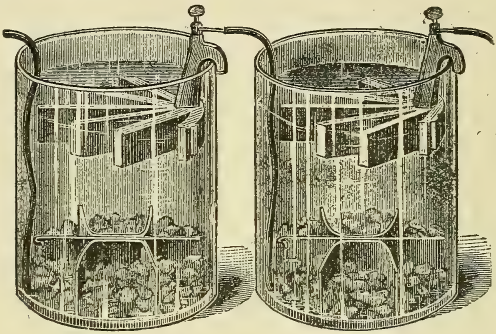


Fig. 21

sulphate of copper solution, and sinks to the bottom, and the displaced copper solution deposits copper on the zinc. Some of the top liquid should, therefore, be taken out every few days by means of a syringe, and water added to take its place. A "hydrometer" (an instrument used to show or measure the specific gravities of liquids) is necessary to indicate the degree of saturation of the upper solution. The cells must be kept free from vibration, or the solutions will mix.

The Gordon Cell.—This is a primary cell, which has lately come into use for the working of central battery exchanges of moderate size, where it is not convenient to use storage cells.

Fig. 22 gives a view of a No. 3 cell having a porcelain con-

taining vessel, and with some of the parts broken away to show the form of the elements. It consists of a perforated cylinder of steel with a bottle-shaped lining, also perforated. On the outside of this are fixed three porcelain lugs, which support a wide ring of zinc. An insulated connecting wire is attached to the zinc, and brought through the cover, as shown. The metal cover supports the whole about half-an-inch clear of the bottom, by means of a screwed stud and terminal passing through an insulated bush.

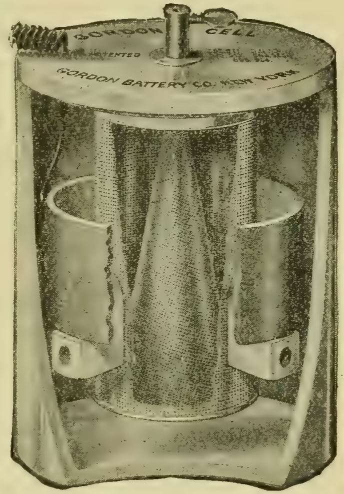


Fig. 22.—Scale $\frac{1}{4}$

The space between the inner and outer shells of the perforated cylinder is filled with the depolarising material, made up of small lumps of black oxide of copper. This is surrounded by the exciting fluid, which is about a 30 per cent. solution of caustic soda. To prevent evaporation and contact with the air, which would spoil the solution, a layer of heavy petroleum is poured over the excitant.

In action, the oxide of copper (CuO) gives up its oxygen to the hydrogen from the caustic soda (NaHO), and metallic copper is deposited on the perforated cylinder. The E.M.F. of the cell is low, being only about ·84 volts, but this is compensated for by its constancy, freedom from local action, and by its low internal resistance.

The outer containing vessel of the No. 3 size is 8 inches high by 6 inches diameter, and its internal resistance is only about ·05 ohm. It will give a very steady current through a high or low resistance, and has a capacity equal to 300 ampere hours.

The cell is really a form of the cell invented by **Lalande,** of which there have been numerous modifications brought out by different inventors, among others that invented by Edison, and known as the " Edison-Lalande " cell, a view of which is shown in Fig. 23. A small plate of zinc and a cake plate of compressed oxide of copper are both supported at a little distance apart by a porcelain lid, the cake of oxide of copper being gripped by two strips of copper connected to two side terminals. The solution used is the same as with the Gordon, and a layer of petroleum is also used to prevent evaporation.

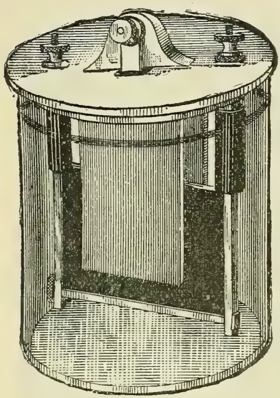


Fig. 23

(2) SECONDARY BATTERIES OR ACCUMULATORS

Since the advent of central battery or central energy methods of working telephonic exchanges, the large amount of working current required at one central point has, from motives both of economy and efficiency, led to the employment of secondary batteries or storage cells at all but comparatively small exchanges.

A secondary accumulator or storage cell is one in which the energy from or of an electric current can be stored up in the form of the energy of chemical combination in such a way that it may at will be reconverted into an electric current. It is analogous to the condenser, except that in the latter chemical action does not take place, and its discharge is only momentary.

Planté's Cell.—The first practical storage cell was introduced by Planté in 1860. It was made up of two thin plates or sheets of lead rolled up together, with strips of felt to prevent contact, and then placed in a glass jar containing dilute sulphuric acid. The arrangement was then " formed," which

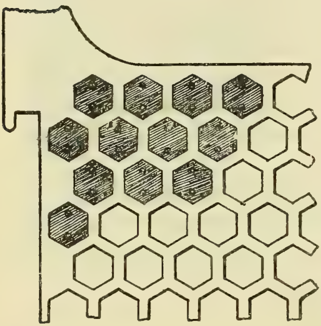
process consisted in passing a strong current from one plate to the other for some time, and then reversing the direction of the current or allowing the cell to discharge itself. This process being repeated several times results in the surfaces of the plates becoming converted into a finely-divided porous or spongy mass. A final charge sent through the cell leaves one of the plates with a coating of brown dioxide of lead. If now the cell is connected in a closed circuit, a current is produced through the cell in a direction opposite to that of the charging current, the coated plate acting like the zinc plate of an ordinary primary cell, and being, therefore, called the electro-positive plate. Current may be obtained from the cell until the coating disappears from the positive plate. As the surfaces of the plates are large and close together the internal resistance is very low, and as the E.M.F. is at first as much as 2·4 volts, a powerful current may be obtained through a small resistance.

Modern Storage Cells.—In modern accumulators the "forming" of the cells, which is an important matter, is to a large extent done artificially, or at least an equivalent effect is obtained, by making the lead plates of the "cellular" or "grid" pattern, and filling the small cells so formed with red oxide of lead or "red lead." This red lead in the process of charging is reduced on one plate (the negative) to a spongy mass of metallic lead, and on the other to peroxide of lead. The small cells or grids in the plates also serve the purpose of keeping the active material from falling away and causing trouble by short-circuiting, etc.

Types of Cells.—The many different forms of storage cells on the market nearly all represent so many different methods of "forming" the plates and of retaining the active material in its proper position on the plates.

Chloride Cell.—The form of storage cell chiefly used in telephony is that known as the *Chloride* cell, made by the Chloride Electrical Storage Co. The term *Chloride* is not used because of any difference in the materials used in the working cell, but simply because chloride of lead and chloride of zinc

are used in the process of "forming" the negative plate. The negative plates, Fig. 24, are constructed by casting a grid of lead (hardened by antimony) round a number of square or hexagon blocks made up of a mixture of the two chlorides mentioned above, and afterwards subjecting the plate so constructed to an electro-chemical process, by which the zinc chloride is dissolved out, and the lead chloride is reduced to a spongy metallic condition. The positive plates, Fig. 25, are made by casting hardened lead plates with a large number of circular holes, in each of which is afterwards packed a roll



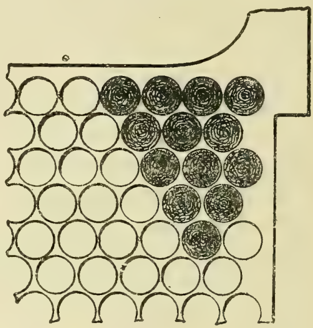


Fig. 24 Scale ¼ Fig. 25

of crimped lead ribbon; the crimping gives the lead a porous character.

The cells are made up of a number of plates constructed as above, and so arranged that there is alternately a positive and a negative plate; but the two outer plates are usually both negatives, so that there is one more of the latter than of positive plates. They are arranged about ¼ inch apart, and are kept at this distance by ebonite "separators." All the positive plates are joined together by thick lead lugs, as are all the negative plates. The supports are so arranged that they keep the lower edges of the plates about ½ inch from the bottom of the containing vessels (which may be of glass,

wood lead-lined, or lead); this is done to prevent short-circuiting by the sediment, more or less of which always settles at the bottom.

New Chloride Cell.—A later form of cell is shown in Fig. 26,

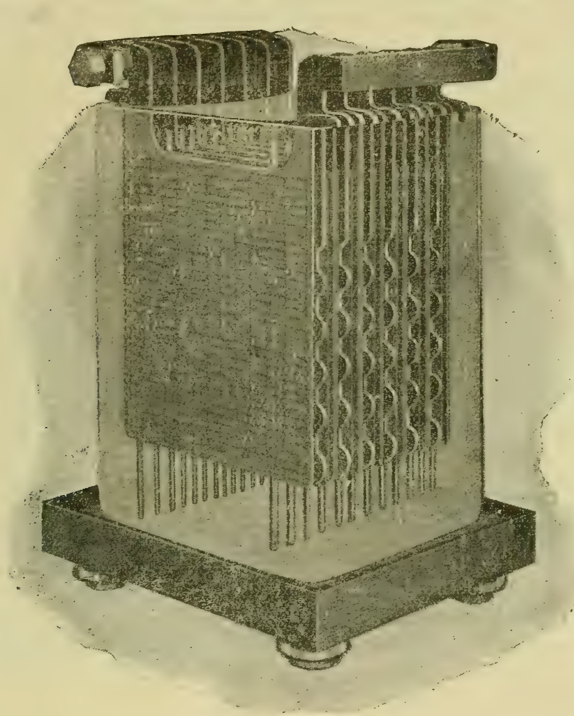


Fig. 26

the negative plates of which are of an altogether different construction. Fig. 27 gives a vertical section of a portion of one of these "exide" plates. The paste P P is filled in between a series of lead grids or bars, L L, of triangular section, so that the paste runs in a zigzag strip from top to bottom of the plate. With this form shrinkage in the paste cannot

affect the contact with the grid, and there is little danger of pieces getting loose and falling out.

The "separators" used are sheets of wood veneer clipped by slit wooden strips, as shown in Fig. 27a. These, fitted between the plates, effectually prevent short-circuiting of the cells, and do not add to the internal resistance as might have been expected.

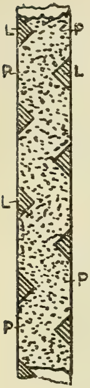


Fig. 27

For telephonic purposes the connections at the tops of the plates are made specially short and thick, as overhearing results if there is any appreciable resistance at this point.

Bus Bars.—These are the thick bars at the top which join together a number of the plates. The process of connecting the plates, which is a kind of soldering, is called "burning."

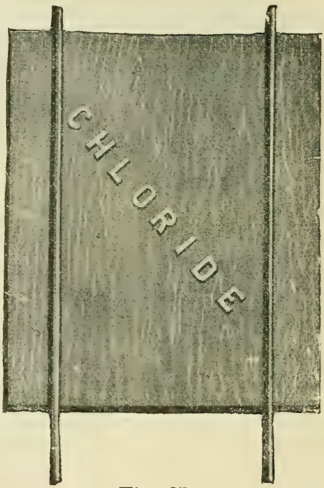


Fig. 27a

The Electrolyte used should be a mixture of about 5 parts of distilled water to 1 part of strong sulphuric acid, this mixture having a specific gravity of 1·19. Various forms of hydrometer are used for testing the specific gravity, which should never be allowed to fall below 1·15.

The chemical changes which take place during discharge are shown by the following formula :—

$$PbO_2 + 2H_2SO_4 + Pb = 2PbSO_4 + 2H_2O.$$

The E.M.F. of a chloride cell when fully charged is 2·5 volts, this gradually falling as current is drawn from the cell; but care must be taken that it does not fall below 1·8 volts, or damage will be done to the cell. Storage cells deteriorate

if allowed to stand without doing work for a length of time, and especially so if not fully charged. They remain in the best condition when regularly charged and discharged.

The cells should be supported on glass or porcelain insulators of the best quality to prevent leakage of current, as shown in Fig. 27*b*, which shows two batteries. All metal-work, and

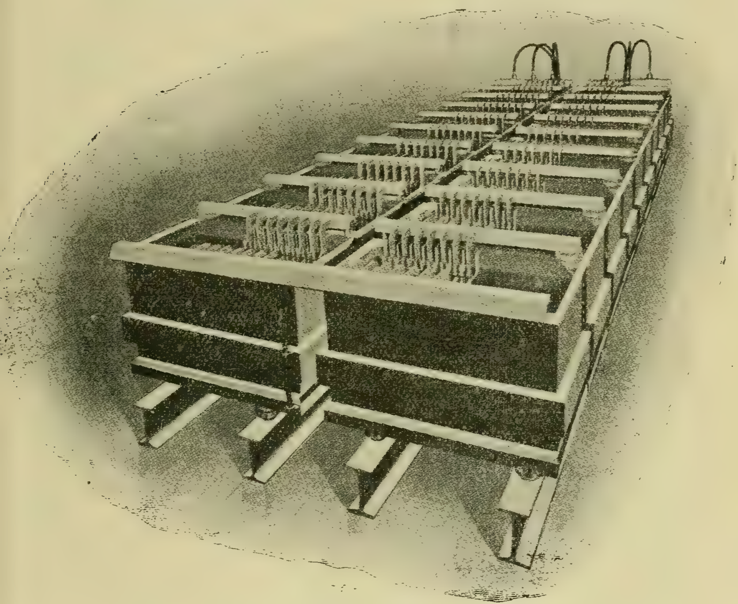


Fig. 27*b*

even woodwork, in the battery room should be protected from the acid fumes by some anti-acid paint or varnish.

The Arrangement of Cells.—When a battery consists of a number of cells, they may be arranged in several different ways; for example, a battery of 12 cells may be arranged all in series or all in parallel; two rows of 6 in series, six rows of 2 in series, three rows of 4 in series, or four rows of 3 in series. In such cases the E.M.F. of the battery is

that of any one row in series, and the internal resistance is equal to that of a series row divided by the number of rows.

To give the *strongest current* through a certain external resistance, the best arrangement is that in which the internal resistance of the battery is *nearest* to the external resistance of the circuit. In most cases this is obtained when the cells are all in series, as the internal resistance is then usually below the external.

Battery Boxes.—When these are needed at subscribers' offices, etc., they should be made so that the lifting of the cover causes both the front and the top of the cells to be exposed, in order that inspection may be easy. The individual cells should be kept apart, and as little as possible of the lead should be bared.

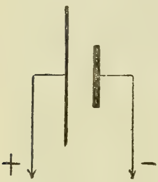


Fig. 28

Cardboard boxes are now very generally used. They are made in two parts — a shallow box, with partitions for the cells forming the base, and a cover which fits over cells and base.

In *Diagrams* a cell is usually represented by two parallel lines—a short, thick one for the zinc, and a longer thin one for the copper or carbon, as shown in Fig. 28. Batteries are represented by combinations of these, as Fig. 29, which shows a battery of four cells joined up *in series*.

Fig. 29

The E.M.F. and internal resistance of such a combination will be four times that of a single cell if the cells are similar.

When a low internal resistance is required, cells are joined up so that all the zincs are connected together, and all the carbons together, as in Fig. 30, which shows three cells so connected *abreast*, or for *quantity*, as it is termed. The in-

ternal resistance of such a combination will be one-third that of a single cell, but the E.M.F. will only be equal to that of a single cell, the combination being only equivalent to a single cell having plates three times the size. It is much better to use cells of large size than to resort to the above arrangement.

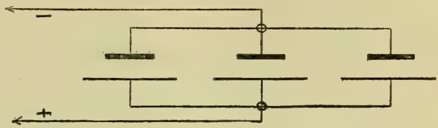


Fig. 30

Efficiency. — The greater the external resistance of a circuit in proportion to the internal resistance of a battery forming a part of the circuit, the greater will be the efficiency of that battery, the fraction of the total energy used up in heating the materials of the battery being then the least.

CHAPTER III

HISTORY

THE first electrical appliance to which the name *telephone* was given was that invented by Philip Reis in 1861. This, however, was only intended for the transmission of musical sounds, although it appears that on some occasions it was successful in transmitting spoken words, but in an accidental manner, the principles involved not being adequately known. These principles were first clearly explained by Prof. Graham Bell in 1876; and as he produced the first practical instrument, he is generally credited with the invention of the telephone.

Reis's Telephone.—Although of little practical use, Reis's instrument is important from a historical point of view. Its working depended upon the fact that an iron rod, when magnetised by a current, gives out a ticking sound. If the current be interrupted very frequently and regularly, and the rod be attached by its two ends to a sounding-board or box, a musical note will be produced of a pitch depending upon the frequency of the breaks in the current. Fig. 31 shows one of Reis's arrangements of this kind, which serves as the receiver. The cover D fitted over the coil *g* and rod *d d* serves to intensify the sound.

The transmitter, Fig. 32, was more complicated. It was so arranged that the voice or a musical instrument sounded into the mouthpiece T should cause interruptions in the current in unison with the vibrations of the sound produced. To accomplish this a large circular opening on the top of the box K is closed in with a stretched membrane, *m*. On the upper surface of this is a strip of platinum, *o i*, connected

to the terminal 2. On the part *o* of this in the centre of the membrane, one corner of a platinum point attached at *b* to an angle-shaped metal piece, *a b c*, just touches it under normal conditions.

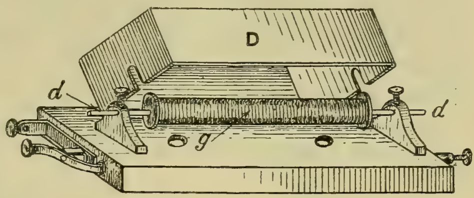


Fig. 31

If the contact *o* forms part of a circuit which includes a battery and the receiver, Fig. 31, and the membrane be set in vibration by a musical sound, the circuit will be interrupted at every vibration. Each interruption produces a sound in the receiver, and a musical sound similar in pitch to the one sounded in the mouthpiece of the transmitter will be given out by the receiver, no matter how distant it may be. The apparatus shown on the sides of the instruments are battery keys for signalling purposes.

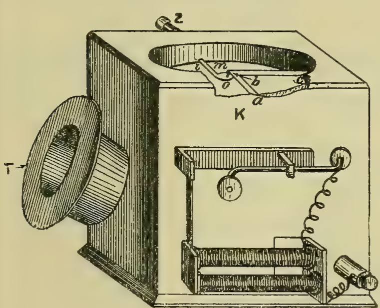


Fig. 32

By such means the *pitch* of any sound may be reproduced at a distance; but this was not enough for the transmission of speech. Pitch is only one of the characteristics of sound, for besides it, sound has *quality* or *timbre,* and degrees of *loudness* or *intensity,* which it was necessary to transmit before human speech could be perfectly transmitted. This cannot be done by an apparatus which employs interrupted currents for its working.

Sound is conveyed through air by a wave motion. The wave motion of water is caused by an up-and-down motion

of the particles of water. Wave motion in air is caused by a movement of the particles of air backward and forward *in a line with* the direction in which the wave progresses. Every different sound needs a different motion of the air particles for its conveyance, and if the characteristic motion of any sound can be impressed upon the air particles at any place, that sound will be reproduced.

This was the problem attacked by Prof. Bell. *Bell's Telephone*, the instrument with which Prof. Bell first succeeded,

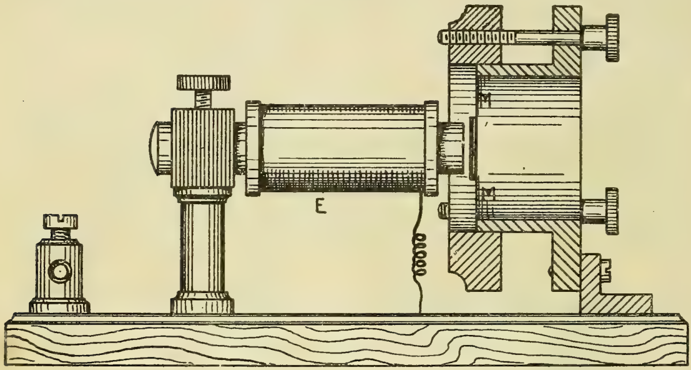


Fig. 33

is shown in Fig. 33, where E is an electro-magnet mounted so as to be adjustable near the centre of a membrane, M, of gold-beater's skin, stretched over the end of a hollow cylinder. A small piece of clock-spring is cemented to the centre of the membrane. Two of these instruments, some distance apart, were joined in a circuit, including a battery, one being used as transmitter and the other as receiver. The action was as follows :—On speaking into the cylinder, the membrane moved in unison with the movements of the air particles. These movements of the magnetic substance in front of the magnet produced alterations in the magnetic field in which the coils were situated. The effect was to cause electrical pulsations or waves to pass

through the coils, the connecting wires, and the coils of the receiving instrument at the distant end, of such a nature that they so affected the attraction between the magnet and the steel spring of the receiver as to set up exactly corresponding movements in its diaphragm to those impressed upon that of the transmitter. These movements being impressed upon the air, a person listening at the end of the cylinder would hear the original sound reproduced, but in a much fainter degree. The characteristics of any sound could thus be transmitted and reproduced.

Gradually improvements were made by Prof. Bell, until

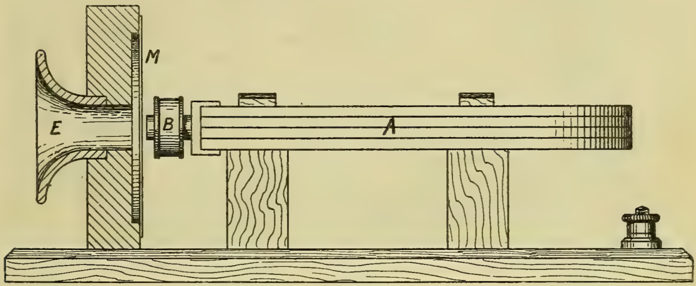


Fig. 34

he arrived at the instrument shown in Figs. 34 and 35, where a compound horseshoe permanent magnet, A, took the place of the original electro-magnet, two small coils of wire, B B′, being fixed on soft-iron pieces attached to its poles. It had been found that no battery was required, its only use being to produce a magnetic field by means of the electro-magnet. The goldbeater's skin membrane had also been discarded, one of thin sheet-iron being substituted.

With this instrument much louder effects were produced; but it lacked portability, to attain which the form shown in Fig. 36 was adopted, and it may be considered the final type. It was made up of a wooden case, in the handle part of which was fitted a bar magnet, N S. On one end of this magnet was fixed a bobbin of wire, the ends of the coil being con-

nected to the terminals at the end of the handle, the diaphragm, D, of ferrotype iron, being clamped close in front of the end of the magnet by a cap in which was turned a funnel-shaped mouth or ear piece with a small opening in the centre.

The action of the later forms is similar to that of the original form, except that the pulsatory currents are wholly developed by the movements of the diaphragm, instead of the movement simply varying a current already existing.

The instruments served both as transmitters and receivers, and came extensively into use in this form. Lines were

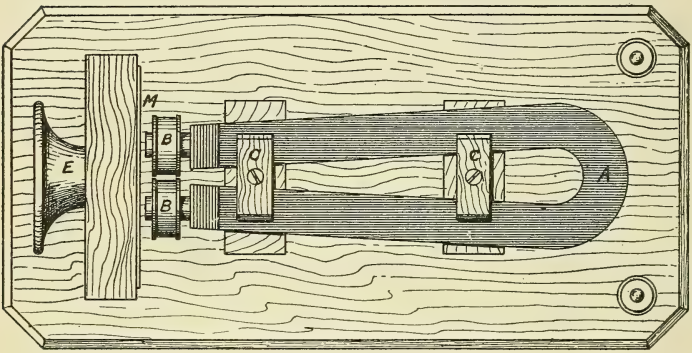


Fig. 35

joined up, as shown in Fig. 37, but two instruments were generally used at each end to save the constant changing from mouth to ear, and *vice versa*.

The received sounds, although very clear, were rather faint, so much so that the telephone would have come but slowly into general use if an instrument to serve as a transmitter, based on a different principle, and giving much louder sounds, had not shortly after been invented.

It had been pointed out by Prof. Bell that the necessary waves of electricity might be produced in another way than the one employed in his *magneto-telephone*, in which the waves

were produced by a varying E.M.F., caused in the transmitter by the movement of the diaphragm. The second method of producing the waves was by *varying the resistance* in the circuit in proportion to the amplitude of the vibrations of the air particles, whilst the E.M.F. remained constant. Bell had shown a method of doing this by means of a platinum wire hanging from the centre of a horizontally-stretched membrane or diaphragm and just dipping below the surface of acidulated water. The wire and the water formed part of a circuit containing a receiver and a battery. On speaking to the membrane, its vibrations would cause the extent of contact between the wire and water to be varied, and so produce corresponding variations and pulsations in the current circulating through the receiver, which latter would reproduce the sound in the manner already described.

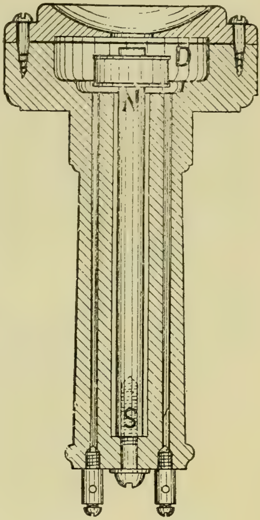


Fig. 36.—Scale ½

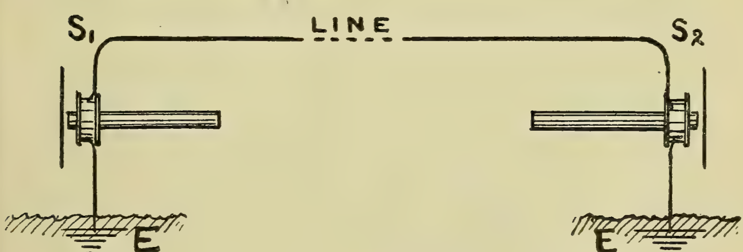


Fig. 37

On the same day that Bell filed his patent, Prof. E. Gray

also filed one with very similar suggestions for producing variations in the resistance of an electric circuit.

Edison's Carbon Transmitter.—Edison, in 1878, was the first to produce a successful instrument based on the variation of resistance principle. He took advantage of the fact discovered by Du Moncel, "that the increase of pressure between two conductors in contact produces a diminution in their electrical resistance." This is eminently the case with carbon, which was the substance chosen by Edison, its great variation of resistance under pressure having been independently discovered by him.

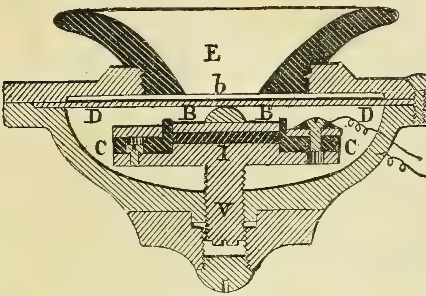


Fig. 38

The instrument Edison finally adopted after many forms had been experimented with, was that known as the "button" transmitter, shown in Fig. 38. D is a mica diaphragm clamped to the iron case by the iron cap, in which is screwed the ebonite mouthpiece E. Pressing against the centre of D is the ivory button *b*, attached to a small disc of platinum, B B. This forms the loose cover of a chamber, with ebonite sides, in which is placed a quantity of lamp-black, I.

The amount of initial pressure on the lamp-black can be regulated by the screw V. The terminals of the instrument are connected one to B B and the other to the metal case, the lamp-black thus forming part of the circuit.

Speaking on the diaphragm causes it to vary its pressure on the carbon, producing corresponding variations in the resistance of a circuit containing also a Bell receiver and a battery. The pulsatory currents thus set up, passing through the receiver, give rise to a reproduction of words spoken into the transmitter. The received sounds are

much louder with this instrument than when a magneto transmitter is used.

Induction Coil.—Edison still further augmented the power of the instrument, especially when used over long distances, by using an induction coil in conjunction with his transmitter. The carbon and battery were connected in series with the primary wire of an induction coil, and the line wire and receiver coils were included in another circuit with the secondary coil, as shown in Fig. 39. The improvement resulted as follows :—As stated above, the working of a carbon transmitter depends upon the variation of the resistance of the circuit in which it is included, when the sound waves

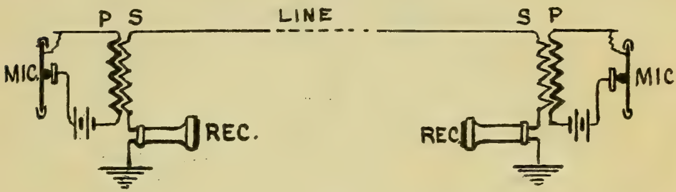


Fig. 39

impinge upon the diaphragm ; the greater the proportional variation to the total resistance of the circuit the louder will be the reproduced sound from the receiver. The variation will be the greater the smaller the resistance of the circuit apart from the transmitter itself. It, therefore, follows that the efficiency will decrease as the distance is increased if the transmitter is included directly in the line circuit. For example, the resistance of a certain transmitter is about 5 ohms, and the variations of resistance caused by a certain sound is, say, 1 ohm ; assuming that the rest of the circuit is 15-ohms resistance, the variation would then represent $\frac{1}{20}$th, or 5 per cent., of the whole resistance. But suppose, now, it is directly in the circuit of a long line the total resistance of which is 1000 ohms, a variation of only $\frac{1}{1000}$th part, or 0·1 per cent., would then be obtained, and the effect on the receiver would be comparatively feeble. If the resistance of the transmitter

were increased to, say, 100 ohms, and the variation was increased in the same proportion to 20 ohms, then in a 1000-ohm circuit we should have a variation of $\frac{1}{50}$th, or 2 per cent., which is twenty times as great. This latter is the principle followed when a common battery is used for exchange working, the current for working the subscriber's transmitters being sent from the exchange. By making use of an induction coil, the resistance of the circuit containing the transmitter can thus be kept very low, and the relative variation made very large. By making a secondary coil of a great number of turns of

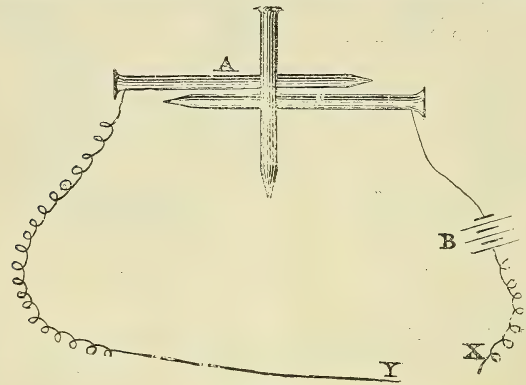


Fig. 40

wire, the currents induced in it by the variations in the primary coil will have a high E.M.F., and will be able to overcome much resistance in the line and instruments at the other end with comparatively little loss of strength.

Microphones.—The next step in the direction of improvement was the discovery by Prof. Hughes of London in 1878 of the fact that *any loose contact* between conductors would act as a telephonic transmitter, owing to the variations of resistance caused between them by the impact of the sound waves. The simple means he employed caused much astonishment. Three nails arranged as in Fig. 40, and joined up with a battery and a Bell receiver, were found to be sufficient

to respond to speech, and were even so sensitive as to render audible the most minute sounds, such as those caused by the walking of a fly, etc. The best effect was obtained with carbon in one shape or another, that given in Fig. 41 being one of the best forms. Two carbon blocks, C, C′, have a cup-shaped hollow made in each, in which the carbon pencil A is loosely held; C, C′ are attached to a sounding-board of thin deal, wires being connected to C, C′ for joining up the battery and receiver.

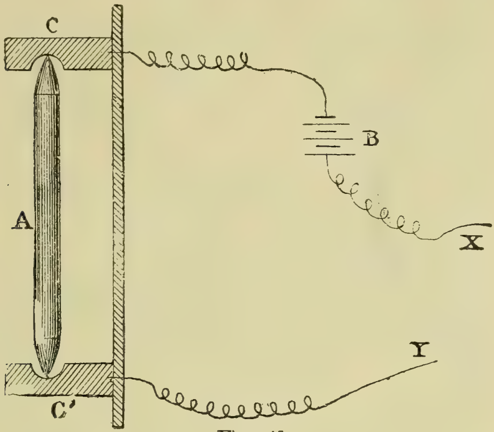


Fig. 41

The complete instrument is shown in Fig. 42, and forms the parent of a very numerous class of telephone transmitters; indeed, nearly all transmitters in use are but modifications or amplifications of some form or other of Hughes' microphone.

Edison's Loud-Speaking Receiver.—This was a very interesting instrument, and was much used at one time. It was based on the fact discovered by Edison, and utilised by him for the construction of a telegraphic instrument, that the friction between a metal and a substance subject to electrolytic action varies in proportion to the strength of a current passing through the points of contact. The telephone re-

ceiver constructed on this principle is shown in Fig. 43. A diaphragm of mica, M, is mounted over an opening in a box, as shown, and a strip of platinum, C (only the end of which is shown), is attached to its centre, and projects at right angles from it. The end of C lies flat on the surface of a chalk cylinder, A, which is moistened with a solution of some easily decomposed electrolyte, such as potassic iodide. The platinum strip C and the metal supports of A are connected in circuit with a battery and a carbon transmitter. On turning the

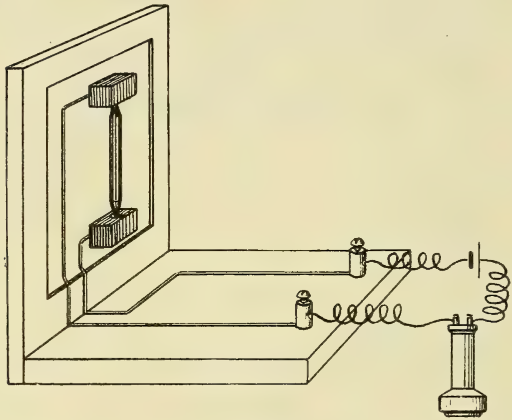


Fig. 42

cylinder by the handle, W, so that the top moves away from the mica disc, the friction (which can be regulated by the screw E) will cause the centre of the disc to be pulled inward. On a current passing, the friction at the contact will be reduced in proportion to the strength of the current, and the disc will partly recover its position. On passing the undulatory currents from a transmitter through the contact, and continuously rotating the cylinder, the disc will be caused to vibrate and give out a sound similar to that directed to the transmitter. In order to moisten the chalk cylinder, it was arranged that on depressing a handle, G, a small absorbent

roller, R, was lifted out of a reservoir, T, containing the electrolyte solution, and brought into contact with the chalk.

When properly adjusted, the instrument was a powerful one, giving out sounds that could be heard all over a large hall. The tone of the instrument, however, being very nasal, left much to be desired, and this, with the necessity of moistening the chalk and turning the handle, led to its discontinuance.

Wireless Telephone.—Many other interesting telephonic

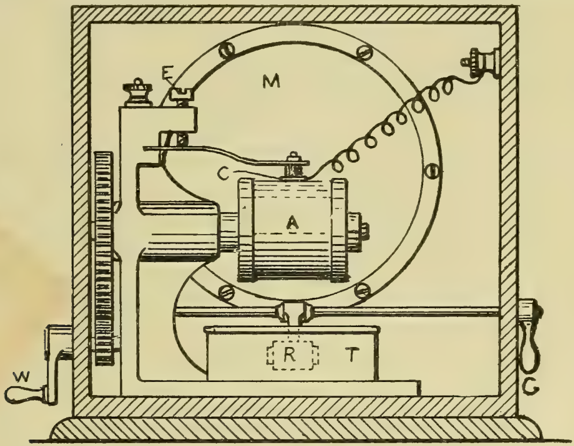


Fig. 43

instruments have since been invented, such as the Graham Bell and Tainter's *Photophone* (1879), in which advantage is taken of the fact that the resistance of some substances, especially a preparation of selenium, is affected by light. At the transmitting station a parallel ray of light is arranged to fall on a polished vibrating diaphragm, from which the light is reflected on to another reflector at the receiving station, which concentrates the light on to the prepared selenium, the latter being included in a circuit containing a battery and a Bell telephone receiver. As the transmitting

diaphragm vibrates, its polished surface curves, and so causes the amount of light which falls on the selenium cell to correspondingly vary, and its resistance to vary proportionately, the sound being thus reproduced in the receiver. Fig. 44 gives a sketch of the arrangement.

In Tainter's *Radiophone* the same effect is produced by heat-rays, these being absorbed by carbon in the form of lamp-black, which is used in the place of the selenium in the Photophone, the other arrangements being similar.

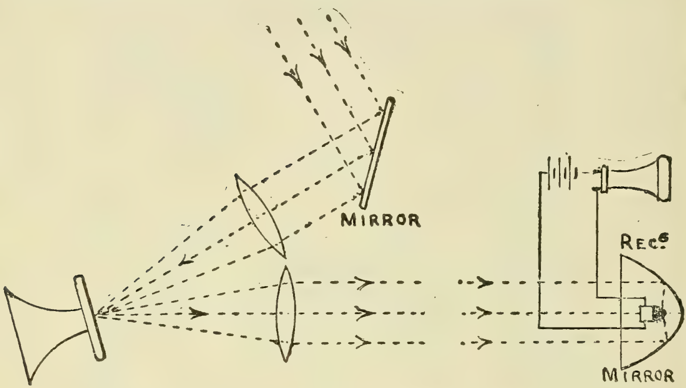


Fig. 44.—Arrangement of Photophone

These are instances of *Wireless Telephony*, of which much has been heard lately, but of which no very practicable application has yet been made. The later systems are similar to the Photophone, but more elaborated.

Dolbear in 1880 invented a *Condenser* receiver which depended for its action on the variation of the attraction between two plates separated by air, when the difference of potential between them was varied. One plate forms the vibrating diaphragm, and the other is fixed. The former is connected to earth or return wire, and the latter plate to the line wire, in the circuit with which is an ordinary carbon trans-

mitter and a battery. Variations of potential are caused on the line when the transmitter is spoken into, and these affect the diaphragm of the receiving condenser.

Telephonic Exchanges.—The telephone at first was used almost exclusively for private purposes, but very early it was recognised by Mr Hubbard, the father-in-law of Prof. Bell, that its usefulness would be greatly enhanced by the establishment of *telephonic exchanges.* Each member who joined one of these had to pay a certain subscription, for which he was supplied with a set of telephonic instruments, and a line wire, which joined him up to a *central office*, where *switch-boards* were fixed, with operators in attendance to connect the line of any one subscriber to that of any other, so that they might converse together.

The first telephonic exchange was established in Boston, U.S.A., in May 1877. In this country they were not established until September 1879, when the invention of the microphone had greatly extended the practical usefulness of the telephone. The writer assisted at the opening of the first, which was in Manchester.

Very few towns in civilised countries are now without their telephonic exchange, and in most large towns business would be completely disorganised by the cessation of its service for a few days.

Later Developments.—At first, telephone exchanges were worked entirely by battery power, and the apparatus used for connecting the lines together was a modification of that used in telegraphy for the similar purpose of varying the connections of the lines with the different transmitting and receiving instruments, as required. Gradually these switch-boards were improved, and new systems for *multiple* working (see Chapter XIV.), were introduced, these greatly extending the capabilities and rapidity of operating, at the same time, however, considerably complicating the apparatus. The apparatus used at the subscribers' premises had in the meantime been considerably improved, more powerful transmitters and receivers being introduced, and the local signalling battery

was replaced by magneto-electric generators capable of signalling over the longest lines.

The connecting lines, which for a number of years were almost exclusively run overhead, and for economy of space and expense were single-wire and earth-return circuits, have in their turn given place to metallic circuit lines, mostly carried underground, the invention of the so-called *dry-core* cables having rendered this feasible by reducing the static capacity of cable wires. This has also resulted in the reduction of maintenance expenses.

Since about the year 1898 another great development, amounting almost to a revolution, has been taking place in telephonic exchange working, by the introduction of the *Common Battery* or *Central Energy* system, which in its most complete form dispenses with any need for batteries at the subscribers' offices, even the current for working the transmitters being supplied from the exchange through the line wires. At the same time, and by the same means, automatic systems of signalling and supervision have been developed, which, while they have resulted in the central office arrangements being converted into a highly complex but effective concentration of mechanism, have reduced to a minimum the work of the operator and of the telephone user.

The progress of the last few years has been mainly confined to (1) the improvement of details in the central energy equipment and arrangements, by means of which the efficiency of working has been improved; (2) in improvements in the transmission results due to the study and investigation of the best conditions of the circuit and of loading (see Chapter XXVI.); and (3) the striking development in wireless telephony consequent on the discovery of methods of transmission by means of continuous electromagnetic waves sent through the ether.

CHAPTER IV

RECEIVERS IN GENERAL USE

The Bell Receiver.—Until about the year 1890 the "single pole" receiver, similar to that shown in Fig. 36, but with a compound magnet like that shown in Fig. 45, and with an ebonite case similar in shape to that of the present "double pole" receivers (Fig. 46) was most extensively used in this country, but it has since been gradually replaced by the "double-pole" form in a similar case, but in which a horseshoe

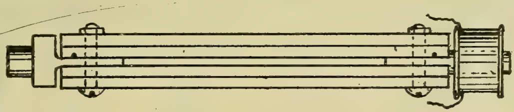


Fig. 45.—Scale ½

magnet is fitted in place of the bar magnet. As shown in Fig. 46, each of the two poles of the magnet is provided with a soft-iron pole-piece on which is fitted an oblong bobbin wound with copper wire of about 4 mils diameter to a resistance of about 60 ohms. The details of construction vary very much with different manufacturers, the chief objects in the many designs being to produce an instrument which will (1) withstand rough usage, such as falls, etc.; (2) prevent the alteration in the relative positions of the diaphragm and the ends of the pole-pieces, due to the very different degrees of expansion by heat, of the magnet and the outer case (when of ebonite); and (3) produce an efficient instrument easily and cheaply manufactured.

The instrument shown in Fig. 46 is used extensively by the National Telephone Co., and has proved very satisfactory.

The case is of nickel-plated brass, over the handle part of which is fitted an ebonite or black fibre sleeve. The double-pole magnet is fixed at the terminal end by a screw passing also through the ebonite terminal block, as shown. The faces of the pole-pieces and the rim of the outer case are ground flat, so as to be all in the same plane, and a brass ring about 16 mils in thickness is clamped in between the diaphragm and the rim of the case to obtain the necessary gap between the diaphragm and the pole-pieces or cores. The ear-piece is of ebonite or fibre, screwed into the brass clamping ring, which clamps the diaphragm in position. The case being metal, there is not much difference between the expansion of it and that of the magnet, so that the gap remains nearly the same with variations of temperature.

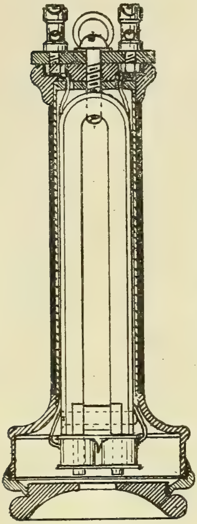


Fig. 46.—Scale ½

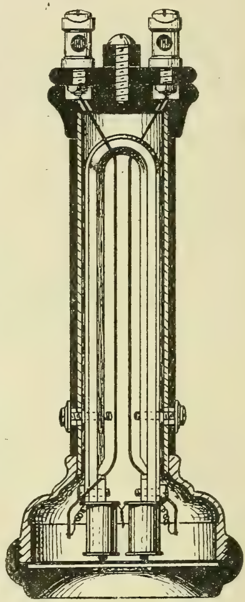


Fig. 47.—Scale ½

The Ericson Receiver.—This receiver, shown in Fig. 47, is also built up with a brass case having an ebonite sleeve. The magnet is fixed to the case by two screws, which pass through the sleeve and case, the holes being slightly elongated, so as to allow of adjustment. On account of the fixing points being near the bell end of the case, the variation of gap with temperature is even less than with the last type. The screws used for clamping

are, however, somewhat unfavourable to comfortable handling, but this is only a slight drawback to a very efficient instrument. To prevent the possibility of the tabs of the connecting cord coming into contact by the turning of the binding posts, a thick strip of ebonite is fixed between the posts by a central screw.

The diaphragm used in this instrument is of tinned iron, about 10 mils thick and 2·12 inches diameter.

*The Kellogg Receiver.**—This receiver illustrates another method of fixing the magnet, etc., so as to overcome the expansion trouble. As shown in Fig. 48, a screwed block is fixed to the polar end of the magnet, and the inside of the

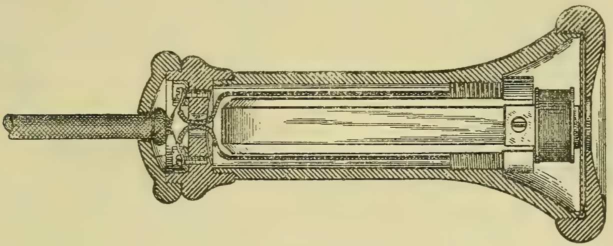


Fig. 48.—Scale ½

ebonite case has a screw cut to correspond. The magnet is screwed in from the mouth of the case, and as the length between the fixing point and the pole ends is small the difference of expansion has little effect. This instrument is provided with a small ebonite cap, which screws over the terminals at the end, thus protecting them from damage or interference, and a thickening at the end of the cords relieves the connecting strands from any strain. Somewhat similar caps were used on some of the earlier English-made receivers, but as they were large and clumsy, and associated with inefficient instruments, they became obsolete. The cap is certainly a good feature, and it is to be hoped it will come into general use.

The Solid Receiver.—This is a form of instrument in which the magnet, pole-pieces, and connecting wires are

* The Western Electric Co.'s C.B. receiver in general use is very similar to this.

embedded in the ebonite of the case so as to form a solid block, thus effectually getting over the expansion trouble, and forming an instrument which will stand very rough usage. It is shown in Fig. **49.** A similar instrument is made by

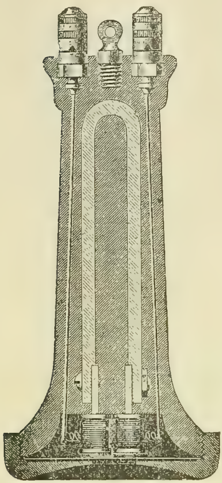


Fig. 49.—Scale ½

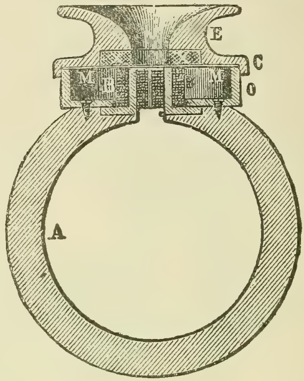


Fig. 50.—Scale ⅔

the Western Electric Co., but is provided with a protecting cap over the terminals.

The Ader Receiver.—In this instrument, a section of which is shown in Fig. 50, a new feature is introduced to enhance the magnetic effect. A magnet, A, in the shape of a broken ring is used, each pole being provided with a pole-piece and a flat coil, B. In the back of the ear-piece a soft-iron ring or washer, X X, is inserted, which intensifies the magnetic field in the centre of the diaphragm by concentrating the lines of force from the pole-pieces, or reducing the reluctance offered to the lines of force, thus making the instrument more efficient. Fig. 51 shows a modi-

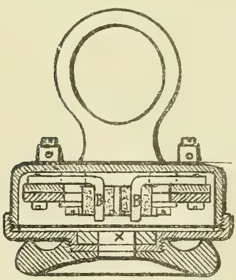


Fig. 51.—Scale ½

fied form, in which a compound flat steel ring (Fig. 52) is magnetised across one of its diameters, N S. With the coils, etc., it is completely enclosed in a small metal case. The resistance of the coils is usually about 120 ohms. The instrument is very handy and efficient, and has been extensively used in France and Belgium, as well as in this country. This form of

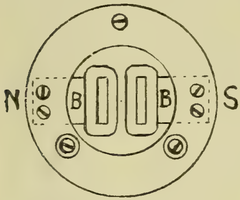


Fig. 52.—Scale ½

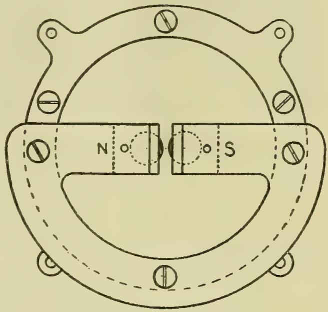


Fig. 53.—Scale ½

magnet (shown in Fig. 52) is now much used in the *hand-micro-telephones* employed extensively in this country.

The Gower Receiver.—This instrument, shown in Figs. 53 and 54, is an old form of receiver which is still somewhat extensively used by the Post Office and the Railway Companies. It is a very large double - pole instrument, with a semicircular magnet fitted in a large brass case, the diaphragm being about 4¼ inches diameter, and correspondingly thick. The instrument, although a powerful one, is too heavy and bulky to put to the ear, and the consequent necessity of using flexible tubes detracts considerably from its effectiveness, as the tubes enclose a large body of air, all of which has to be set in

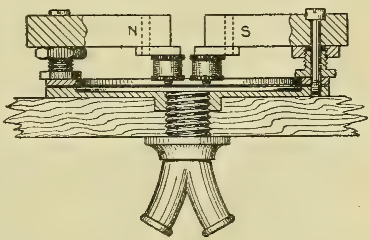


Fig. 54.—Scale ½

vibration. Consequently, the amplitude of the vibrations which reach the ear is appreciably lessened. These disadvantages have led to its gradual displacement by other forms of receivers.

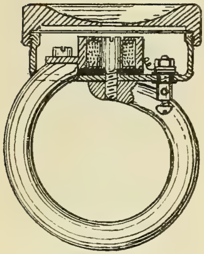


Fig. 55.—Scale ½

D'Arsonval Receiver.—In most forms of the double-pole receiver each pole of the magnet is fitted with a coil. In the D'Arsonval both poles are utilised, but only one coil is used. As shown in Fig. 55, one pole is furnished with a round coil, B, and the other is attached to a soft-iron cylinder, T, which fits over it, thus forming a box electro-magnet, which concentrates the lines of force due to the operating currents and the magnet in the centre of the diaphragm.

The Collier Receiver.—This is also a double-pole receiver in which only one coil is used. This coil, with its core, is altogether detached from the magnet, the latter being used to polarise the core. The construction is shown in section in Fig. 56. The coil is fixed in a central block of ebonite, and side cheeks of ebonite screwed on to this block serve to clamp two soft-iron diaphragms very close to the two ends of the core. On the outside of these cheeks the two magnet poles are fixed in contact with two soft-iron adjusting screws brought very near the outer faces of the diaphragms. The top of the instrument is shaped for fitting to the ear, and is put into communication with the internal spaces between the diaphragms

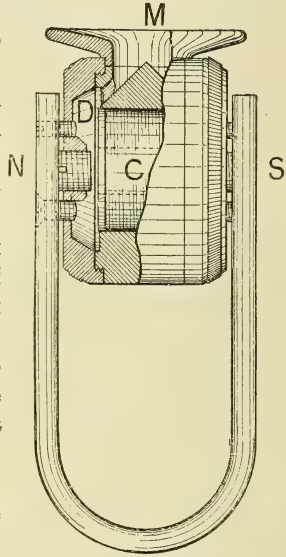


Fig. 56.—Scale ⅓

and the sides of the bobbin by small holes, as shown. The ends of the coils are connected to terminals, A and B.

The diaphragm and coil being in a strong magnetic field, the core of the coil is strongly magnetised by induction. The instrument is efficient, but is too bulky for ordinary use. It is, however, often used as a loud-speaking instrument.

The Watch Receiver.—This is a double-pole receiver of a neat, light, and compact form, a little larger than an ordinary watch. Fig. 57 gives an interior view of one form.

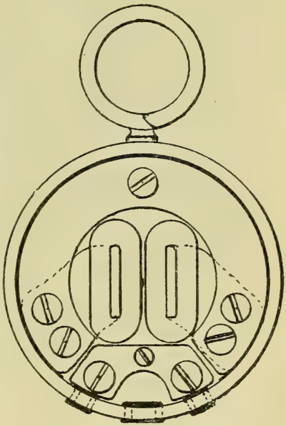


Fig. 57.—Scale $\frac{2}{3}$

Hand-Micro-Telephone.—The receivers used in connection with the hand-micro-telephone type of instrument, now so commonly employed in this country, are of a similar type to Fig. 51, the magnets being either of the ring pattern, as shown in Fig. 52, or similar to those of Fig. 57.

Relation between Strength of Magnet and Size of Diaphragm.—M. Mercadier conducted a series of experiments having for their object the determination of the above problem. From these experiments he arrived at the following conclusions :—

1. For every telephone of a given magnetic field there is a thickness of diaphragm which gives a maximum effect. The stronger the magnet the thicker should be the diaphragm.

2. The thickness of diaphragm being known for a certain magnetic field, there is one diameter for the diaphragm which gives the best result. This diameter will be greater the stronger the magnetic field.

3. That arrangement of magnet and coils will give the best result in which the greatest number of lines of force run through the coil in a direction at right angles to the plane

of the coil, and in which these vary most with any movement of the diaphragm.

From the above researches, M. Mercadier was led to devise a very small and light receiver, which he called the *bitelephone*, and which he claimed to be as effective as the ordinary form. A full-size section of one ear-piece is shown in Fig. 58. The ebonite case is made up of three parts, B, E, and C, screwed together. The magnet is a curved one, similar to that of a watch receiver, and is provided with two round bobbins having soft-iron cores which screw into the magnet poles. The whole of this is mounted on an iron disc, A, so that by means of the screw *a* the ends of the magnet cores can be adjusted very near to the iron diaphragm D. The cap C has a projection (with a removable cover of india-rubber) for fitting in the ear.

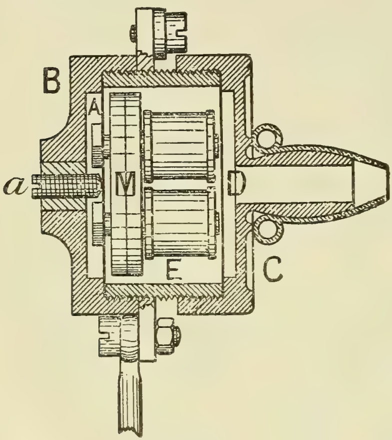


Fig. 58

Two such instruments as above are fitted on the two ends of a piece of steel wire, by means of which the pressure on the ears can be adjusted. The pair thus connected are used like the ear tubes of a phonograph. The single instrument weighs but $1\frac{3}{4}$ ounces, and the pair with steel wire $4\frac{1}{4}$ ounces. In spite of its lightness and convenience, however, it is not now much used, as it has not proved so efficient as expected.

Operators' Head-Gear Receivers.—These are used to allow exchange operators to have both their hands at liberty for operating. They are merely ordinary watch receivers fitted in aluminium cases for lightness, and provided with springs to fit over the head. Fig. 59 shows the most common form,

and Fig. 60 another, provided with an elastic rubber band and buckle.

Loud-Speaking Receiver.—Fig. 61. This is used for com-

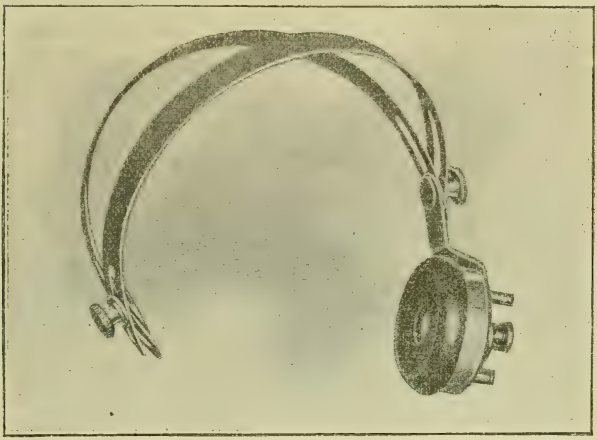


Fig. 59

munication between offices in the same building, so that calls may be made without any call bell being needed. It is merely a large double-pole receiver provided with a magnifying

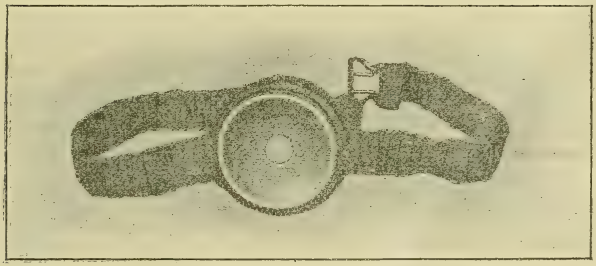


Fig. 60

trumpet, and arranged so that it may be screwed to a wall or upright.

General.—The sizes of the different parts of receivers vary in different makes, but for those in general use the diaphragms may be taken as from about 9 to 12 mils in thickness (generally 10), and from 2 to 2·3 inches in diameter, the free part varying from about 1·8 to 2 inches in diameter. The resistance of the two coils varies from about 90 to 125 ohms for local battery working, and from about 50 to 75 ohms for central battery working, the most common being about 60 ohms. The coils are wound with silk-covered copper wire, of about

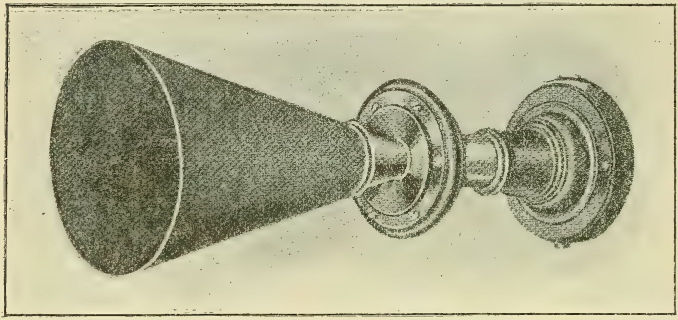


Fig. 61

5 to 7·5 mils in diameter, for C.B. working, while for local battery receivers wire from 3 to 6 mils is used. The bobbins used are mostly of thin brass, but sometimes they are of fibre or wood.

Sensitiveness of the Receiver.—In order to show the extreme sensitiveness of the Bell receiver, Dr Werner Siemens connected a receiver wound to a resistance of 110 ohms in circuit with the secondary wire of an induction coil; in the primary circuit he connected a single Daniell cell, a resistance of 50 megohms (50,000,000 ohms), and a mechanical interrupter. Under these circumstances, the current being only $\frac{1·08}{50,000,000}$ $=$ ·000,000,0216 amperes in strength, a loud sound was given out when the current was rapidly interrupted, and a sound

could be heard even when the secondary coil was slipped off to the extreme end of the primary coil, the instrument being so constructed as to allow of this.

Polarising Magnet.—The fact that, in order to obtain the best results, the cores of receiver coils require to be polarised, either by a permanent magnet or by a direct current, is explained as follows :—The stress between the poles and the iron diaphragm varies as the square of the intensity of the magnetic force in the space between them. It is clear that to get the greatest vibration in the diaphragm the intensity of the pull must vary as much as possible. If H represents the strength of the field due to the magnet, and h that due to one of the speaking waves, then the pull on the diaphragm will vary between $(H+h)^2$ and $(H-h)^2$. The difference between these amounts to $4Hh$, which represents the difference in pull on the diaphragm. If there were no polarising magnetism the pull or stress on the diaphragm would vary between o and h^2 ; and h being a very small quantity, its square will also be very small, and very much less than $4Hh$, in which the comparatively very large value of H is included.

It will be seen from the above that the intensity of action of a receiver is proportional to the strength of the permanent magnet, and it is important, therefore, to see that the strength of the magnets is maintained.

Reinforced Receiver Cases.—Receiver cases have recently been introduced which have been rendered practically unbreakable by layers of canvas which have been embedded in the ebonite before vulcanising. This canvas takes up any shock and prevents the cracking of the ebonite.

Dr Traun's Material.—This material is merely a very high quality of vulcanite. The ear-pieces of receivers are made of it, and as it is very tough and strong it withstands the rough usage to which this part of a receiver is peculiarly liable.

CHAPTER V

TRANSMITTERS IN PRACTICAL USE

As stated in Chapter III., the transmitters used in common practice are all variations of some form of Hughes' microphone, and they may be roughly divided into three classes—viz. (1) the Button Carbon; (2) the Pencil Carbon; and (3) the Granulated Carbon.

The prototype of the first class is the "Blake," of the

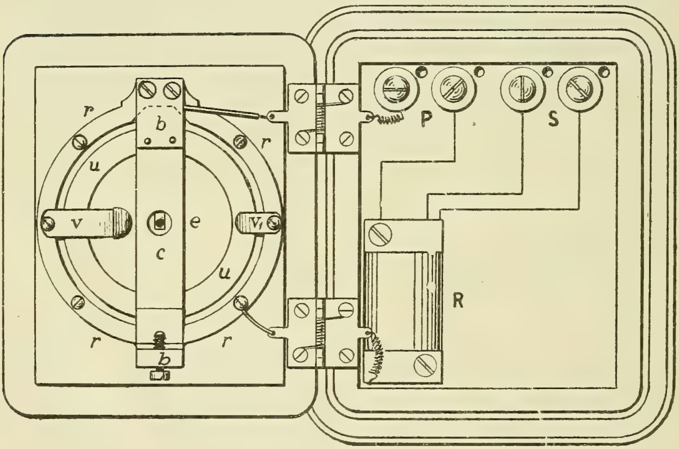


Fig. 62

second the "Crossley," and of the third the "Hunnings," transmitter.

Blake Transmitter.—This was invented very soon after the microphone, and for a number of years was more extensively used than any other kind of transmitter. It has now, how

ever, given place to some form of the more powerful granular transmitter. When properly made and adjusted it gives a very pure reproduction of the voice, but is not sufficiently powerful for long-distance work, and possesses the demerit of requiring adjustment at times. Fig. 62 shows the inside of the instrument when open, and Fig. 63 a section through the centre of the transmitter.

The chief feature of the instrument was a small pellet of platinum (attached to the end of a light spring, *f*) which intervened between an iron diaphragm and a small round carbon block fixed in a brass socket, *p*, and supported by another spring, *g*. The pressure on the pellet could be regulated by the screw *n*. The two springs formed the electrodes for the primary current. The inertia of *p* caused considerable variation of pressure between the pellet and the carbon when the diaphragm was vibrated by the voice waves.

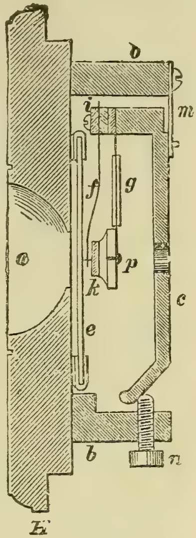


Fig. 63

Transmitter of the Société des Téléphones.—This, although not much used, is interesting as involving an important principle. It is a kind of double "Blake," in which the effects produced by the movement of the diaphragm are doubled. Fig. 64 shows the connections: *a a* is the diaphragm and *b c* two carbon blocks rigidly connected to it, the latter by an insulating half ring, *d*. Between *b* and *c* rests a platinised metal cone, fixed at one end of a pivoted and balanced arm. J is a triple-wound induction coil of two primaries and one secondary.

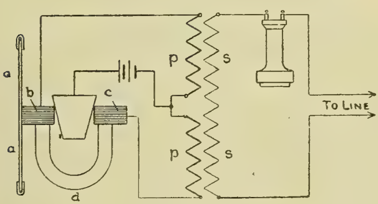


Fig. 64

The battery being joined up as shown, any movement of the diaphragm causes an increase of pressure on one carbon and a decrease on the other, so that the current through one carbon is increased and through the other decreased. As, however, the currents are arranged to pass in opposite directions through the two primary coils, a double effect in the same direction is induced in the secondary.

Pencil Microphones.—These are generally various combinations of Hughes' carbon pencil microphone. The tendency has been to increase the number of pencils used, and these are generally joined up in multiple, so as to reduce the resistance and lessen the disagreeable sounds due to accidental breaks

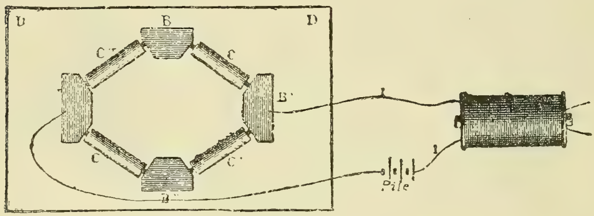


Fig. 65

in the loose carbon contacts when subjected to slight jars. They are rather more powerful than the Blake, but not so good as the granular type.

The *Crossley* was the first pencil microphone brought into practical use. As shown in Fig. 65, it consisted of four carbon blocks B, B′, B″, and B‴, cemented to a thin pine sounding-board, D D. Between these blocks were four carbon pencils, C, C′, C″, and C‴, the ends of these having been turned down so as to fit loosely in holes in the blocks. The two side blocks form the electrodes, and the current divides through the two sets of pencils.

The Gower.—The pencils of this transmitter are eight in number, with nine fixed carbon blocks, arranged, as shown in Fig. 66, in the form of a star. The two outer sets of blocks are screwed on to two copper pieces, S and S′, to which the

outer connections are made. The operating current thus divides through four pencils in parallel and two sets in series. This instrument was extensively used in this country, and especially by the British Post Office, and gave great satisfaction.

The Ader.—This, as shown in Fig. 67, has twelve pencils and three blocks, so that the number of contacts is twenty-four as compared with eight in the Crossley. It has been very extensively used in France, and has given very good results. It has also been extensively used for the transmission of music, etc., from theatres.

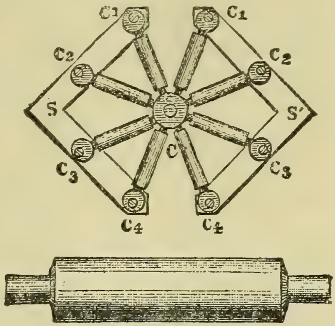


Fig. 66

There have been many other forms of the pencil microphone, which, however, are not now of sufficient importance to warrant a description.

Granulated Carbon Transmitters.—These are, undoubtedly, the most powerful transmitters, and for this reason, and

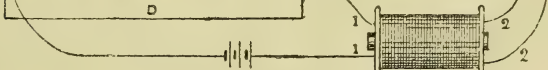


Fig. 67

owing to their general adaptability, have nearly supplanted all other forms for general use. For a long time they laboured under the disadvantage of what is known as "packing," which resulted from the gradual settling down and consolidating of the carbon granules, so that the loose contacts, upon

which their efficiency depended, were no longer existent, and the carbon conducted as an ordinary solid conductor.

Many different forms of granular microphones have been devised, but nearly all represent different methods of getting rid of the packing difficulty. They all contain crushed retort carbon or oven-coke sifted through wire gauze so as to obtain even grains of about the size of those of fine gunpowder. A quantity of this is enclosed in a small cell between a flexible diaphragm and a fixed block of carbon. Probably the best method adopted for the prevention of packing is repeated sifting, to ensure that all the granules used in a transmitter are as nearly of the same size as is practically possible.

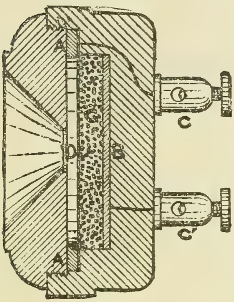


Fig. 68

On account of the number of loose contacts the variation of resistance is very great, which explains their power. Sometimes the granules are impregnated with mercury to lessen their resistance.

The Hunnings Transmitter.—This was the first of the type. It was made up of a round wooden case about 3 inches in diameter, shown in section in Fig. 68. In the bottom of a recess, G, turned in the wood, a thin plate of carbon, B, was cemented, a wire connecting it to terminal C′. At the front of the recess a platinum foil diaphragm, D, was clamped by the brass ring A A and screws—A A being connected to terminal C. The recess formed was filled about three-fourths full of the carbon granules. A cap with a funnel mouthpiece is then screwed on, as shown. The bottom of the funnel had generally a piece of wire gauze, or some crossed wires, fixed over it, to prevent the foil being damaged by thoughtless persons poking it with pencils, etc. The instrument was generally held in the hand while using, and could, therefore, be easily shaken to prevent consolidation. It was at first used without an induction coil, but works much better with one.

The Moseley.—This was similar to the Hunnings, except

that instead of a platinum diaphragm one of thin pine wood was employed, having fixed to its centre a thin block of carbon connected by a fine wire to one of the terminals.

The Solid-Back.—This transmitter, invented by Mr A. C. White in America, has achieved great success owing to its great power and freedom from packing. It is made by the Western Electric Co., and is very extensively used in America, and also in this country.

Fig. 69 shows a section of the instrument, and Fig. 70 a

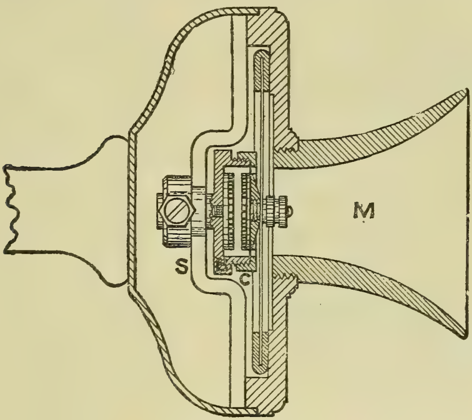


Fig. 69.—Scale $\frac{2}{3}$

back view of the transmitter proper as made for attachment to a moving arm. The small brass cell G is provided with a screwed cover, which serves to clamp a small flexible mica disc, to the centre of which is clamped a thin carbon electrode rather smaller than the inside of the brass cell.

This electrode is faced by another one of carbon, fixed to the back of the cell. Both electrodes are electroplated, and soldered to their supports.

The cell is rigidly fixed to the arm *s*, which extends across the instrument. The mica disc is clamped by the screw shown to a comparatively large ordinary aluminium diaphragm

with an india-rubber ring round its edges, held in position and damped by means of two flat steel springs clamped to the rim of the casting, and with their ends tipped with felt or rubber pads, which bear on the outer part of the diaphragm. The sides of the cell G are lined with paper, and the space left (shown in white in the figure) is filled about three-fourths full with carbon granules. If, however, the transmitter is to be used for common battery working, only about one-half the amount of granules (8·8 grains) is used, in order to increase the resistance.

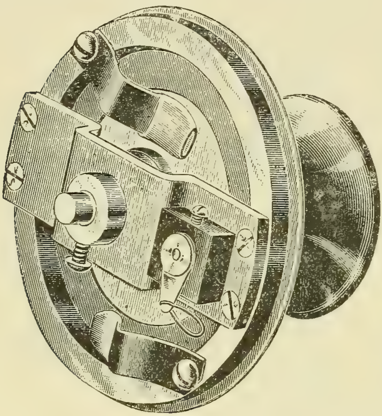


Fig. 70.—Scale $\frac{3}{5}$

The diaphragm is $2\frac{1}{2}$ inches in diameter and ·022 inches in thickness, and the carbon cell is $\frac{5}{8}$-inch internal diameter. The normal resistance of the ordinary instrument is about 30 ohms, and of the common battery form about 55 ohms.

The Deckert.—This is a very successful instrument, made by the General Electric Co. in this country. The special feature of the instrument is the shape of the front face of the fixed carbon electrode. This, as shown in Fig. 71, is formed into a number of square-based pyramids. The instrument is sometimes called the Hunningscone transmitter. The junctions of the bases of the pyramids of one row are opposite the middle lines of the bases in the adjoining rows. Only the centre portion of the block is used, the other part being covered with a thick pad of cotton wool. It will be noticed that all the tips of the pyramids in a circle of about 1-inch diameter are cut off, and little tufts of floss silk are attached. They serve to prevent short-circuiting against the

outer carbon diaphragm, to damp the vibrations of the latter, and to prevent "packing" by retaining portions of the carbon granules entangled among the filaments. As the instrument is not altogether free from the "packing" trouble, it is arranged so that the transmitter may be rotated a half-turn occasionally, when used as a fixed transmitter.

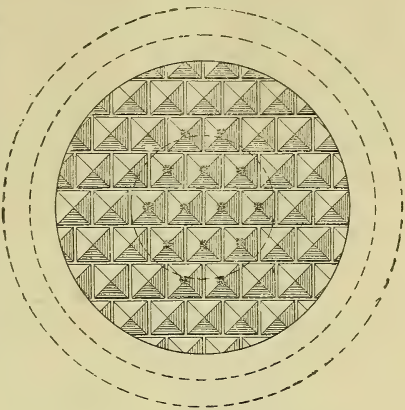
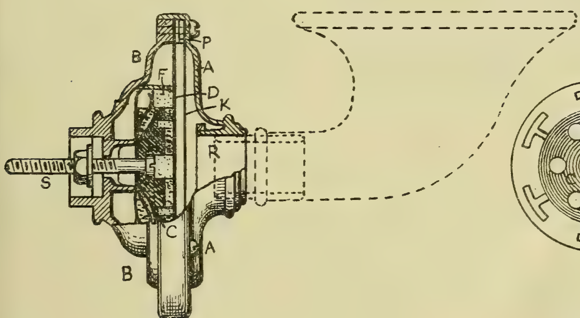


Fig. 71.—Full size

The Ericsson. — This also is a highly successful transmitter. It is made by Messrs Ericsson of Stockholm, and is extensively used all over the world. There are two or three forms of the instrument. Fig. 72 gives a sectional view of the latest. Comparative tests have shown that it is at least the equal of any transmitter in use for long-distance work, with local battery working.



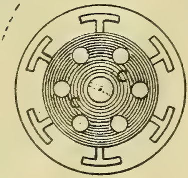


Fig. 72 Scale $\frac{1}{3}$ Fig. 73

The instrument is made up in an aluminium case, A and B, made in two parts. The back part of the case B has a recess, in which fits a $\frac{7}{8}$-inch round carbon block, C, $\frac{1}{4}$ inch thick. The front face of this block has seven holes drilled in it—one in the centre, in which fits the head of the long, clamping and connecting screws, and six other holes, as shown in Fig 73 (which gives a separate view of the carbon block). Tufts of cotton wool are fitted in each of the seven holes. These tufts, when in position, press on the carbon diaphragm D, which is of thin carbon, $2\frac{1}{4}$ inches in diameter and 40 mils thick. A sort of sleeve of soft felt, F, fits over the edge of the carbon block, and is also pressed against the diaphragm D by the heads of six bronze springs, which are all joined together at the centre, and clamped with the carbon block. Six recesses are made in the latter to allow the springs to work freely. The carbon block and screw, S, are otherwise insulated from the case B by a mica washer, M, and bush, H, and by an ebonite washer, W, at the back. Rings of blotting-paper, P, are used to clamp the diaphragm, and they also serve to clamp in front a membrane of oiled silk, K, which prevents the moisture of the breath, etc., reaching the diaphragm. An ebonite or soft-rubber funnel fits into the recess R. About five grains of carbon granules, G, are put in the recess left at the back of the diaphragm. The normal resistance of this transmitter is about 100 ohms, and in working it varies between about 50 and 170 ohms.

Another form of Ericsson is similar to this as regards the carbon block, etc. (except that the six outer holes in the block are missing); but the diaphragm is of ferrotype iron (about 12 mils thick), on the inner face of which is fitted a gilded thin metal dish, the surface of which has about thirty-eight indentations pressed into it in two concentric rings. These indentations are projections on the other side. They project into the carbon granules, making good contact, and preventing "packing."

Operators' Transmitters.—The most convenient form of transmitter for the use of operators in telephonic exchanges is the so-called *breastplate* form, as it is always in the most

convenient position for speaking, whilst leaving both hands at liberty for making connections.

Fig. 74 shows the form first made by Ericsson & Co. The transmitter is pivoted on its axis with the diaphragm vertical, so that the distance of the india-rubber or ebonite funnel from the mouth may be readily adjusted. The whole is mounted on an aluminium breastplate suspended from the neck by an adjustable band. One of the connections to the transmitter is made through a spring which normally presses on a metal piece fixed on the ebonite rim of the case, but when the case is revolved, so that the funnel is out of position, the contact is broken, and the transmitter current is cut off.

Fig. 74

A late form of breastplate transmitter made by the Western Electric Co. is shown in Fig. 75. A solid-back transmitter is employed, to which is fitted a long ebonite mouth-piece, provided with a universal ball-joint, so that it may be adjusted or swung round out of the way when not required. This instrument is adopted in common battery exchanges, and is very powerful.

It is usual to allot a particular breastplate set to each operator in an exchange, the operator being responsible for its safe-keeping and cleanliness.

Transmitter-Testing.—This is usually done through an actual long line or sometimes through an artificially made up line. The latter is made up of a number of coils of wire, each having a resistance representing a certain length of line and a number of

condensers also of a capacity equal to that of the same section of line, the condensers being connected as branches to the coils, which are joined in series (as shown in Fig. 76) so that the whole

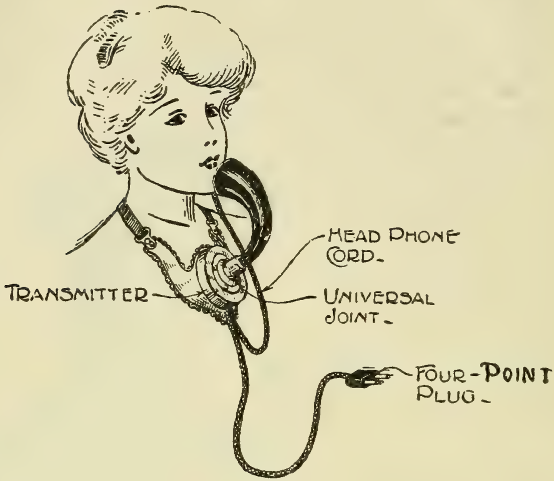


Fig. 75

represents a line (open or cable) of a certain length, both in resistance and capacity. Plugs are used to join up the various sections for test. The coils should be wound non-inductively, as are those of a Wheatstone bridge, so that they have no

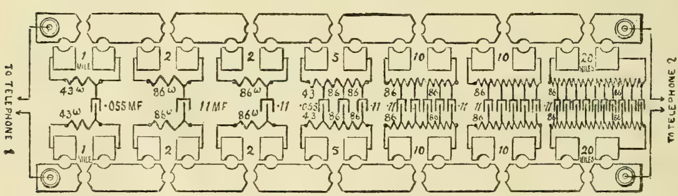


Fig. 76.—Artificial Line, 50 Miles Standard Cable

inductance, unless such is specially required, in which case they are wound inductively.

Transmission Tests.—The testing arrangements installed

at the Head Office of the National Telephone Co. in 1904 were very complete and were adopted by the British Post Office in determining the standard transmission tests to which all parts of the instruments and lines of the Company were to conform at the time of their purchase by the Government.

Standard Cable.—The chief item of this testing outfit consists of a dry-core cable (see Chapter XXV.), 460 yards in length and containing 204 pairs of wires of 20 lb. gauge. This cable (or rather a 1-mile length of it) has been adopted as the standard unit to which all classes of lines and apparatus can be compared as to what may be called their "talking resistance or reactance." Particulars of the electrical qualities of this standard cable will be seen from the table of transmission equivalents of lines, aerial and cable, in the Appendix. It is so arranged that lengths of from 0·1 to 52 miles (which latter figure is about the maximum length of this cable which, with standard instruments, will give commercial speech) can be introduced, as desired, between two sets of instruments, so as to form a basis of comparison against which the transmission efficiency of any parts or sets of telephone instruments or lines may be balanced and their values adjudged in terms of miles of the Standard Cable.

For the standards required by the Government see the terms of agreement given in the Appendix.

Artificial Copies of Standard Cable.—In order that the necessary transmission tests may be made in any part of the country portable artificial cables are made up in the manner shown in Fig. 76, these cables being accurately calibrated against the standard and sealed to prevent alteration.

Testing Receivers.—The arrangement is also used for testing and comparing receivers, of course keeping to the same transmitter at the other end of the line.

The commercial speaking limit of the best class of instruments is about 50 miles of the 204-pair cable, this length having a resistance of $84 \times 50 = 4200$ ohms, and an inductive capacity of $\cdot 055 \times 50 = 2\cdot 75$ microfarads.

Dynamometer Tests.—By using a very delicate dynamo-

meter, Prof. Cross of Boston made direct measurements of the strengths of the currents generated in the secondary wire of a transmitter induction coil by the variations in the primary coils, and has been thereby able to compare the power of different transmitters—a matter of difficulty when judging by the ear alone, which, however, is still the method generally adopted.

Three instruments—Edison's, Blake's and Hunnings'—were thus tested, an organ pipe sounding under an equal pressure of wind acting on the transmitters at equal distances.

The strengths of the currents registered were as follows :—Edison, ·072 milliampere; Blake, ·132 milliampere; and Hunnings, ·556 milliampere. This shows a marked superiority in the case of the Hunnings, which bears out practical experience.

Experiments were also made by sounding the different vowel sounds, the results coming out in about the same proportion as above. It would be interesting to have other transmitters tested to show their relative efficiency. By Mr Duddell's Thermo-Galvanometer the testing of such apparatus has been rendered easy of accomplishment. This instrument depends for its working upon the heat generated by weak alternating currents in a very fine strip of gold or platinum foil cemented to a strip of glass, and fixed close to a thermo-electric pile. By this means very delicate currents, such as telephone currents, can be measured and compared.

Transmitter Induction Coils.—Experiments made by M. Abrezol of Geneva, on lines of varying length, to determine the best dimensions to be given to induction coils in order to obtain the best effects, resulted in the recommendation of a coil of the following dimensions :—Primary wire, 180 turns of wire 24 mils diameter (23 gauge), giving a resistance = ·5 ohms. Secondary wire, 4200 turns of wire 6 mils diameter giving a resistance = 250 ohms. Experiments made by Mr Preece resulted in corroborating the above figures. For full particulars of these experiments, and of others with different transmitters, and also for particulars of many other receivers and transmitters, see Messrs Preece & Stubbs' "Manual of Telephony."

Later practice, however, does not appear to bear out the above figures, for in recent years the resistance of the secondary coil has been materially reduced, with considerable advantage to the speaking. The thickness of the wire used in winding has also been much increased, with increase in the size of the coil. The coil employed by the National Telephone Co. for their local battery transmitters has a primary wire of 20·5 mils wound to a resistance of 1 ohm, and a secondary wire of 10·75 mils wound to only 25 ohms. The bobbin has a winding space of about $2\frac{1}{4}$ inches, and a core of a bundle of 22 mils iron wire about $\frac{5}{16}$ inch diameter. For central battery working the two windings of the coil are 15 and 30 ohms.

Humming Effect.—A very curious effect may be produced with a good form of granulated carbon transmitter worked by a battery of three or more cells. If a receiver in circuit with such a transmitter have its ear-piece brought close to the transmitter, and then slightly jarred, a musical note will be given out, caused by the action and reaction of the two instruments on each other. The sound will also be set up in other receivers in the same circuit, and may be loud enough to be heard all over a room, so that it can be used to call a subscriber's attention when his receiver is left accidentally in circuit with the line.

The matter has been investigated by Mr F. Gill, who has found that if the receiver connections are reversed the note given out changes, becoming higher or lower in pitch. Adding capacity across the receiver terminals or inductance to the circuit, lowers the pitch of the note, adding resistance to the circuit raises it. The alteration of any part of the circuit electrically, or of the distance between the diaphragms, causes an alteration in the pitch of the note.

CHAPTER VI

SUB-STATION APPARATUS

ALTHOUGH signalling between telephone stations has been accomplished by means of the telephone instruments themselves, vibrations being set up in the diaphragm of the distant receiver by rapidly making and breaking a battery connection to the line, the universal practice is to use some form of electric-bell signal, operated either by a battery, or by electricity generated mechanically by means of a magneto-electric machine.

The signalling and switching apparatus thus required led to the adoption of what are called *switch-bells*, in which the apparatus is compactly arranged, and the necessary switching is accomplished by the aid of an *automatic switch*, which consists of a pivoted lever so arranged that the act of hanging the receiver on one end of it, when a conversation is finished, changes the connection from the telephone apparatus on to the signalling device, and disconnects the transmitter battery circuit, so as to prevent the battery working to waste.

Electric Bells.—As these are much used in telephony for signalling purposes, especially on private lines, a short description is desirable. The term " electric " is generally applied to those bells which are actuated by batteries, those operated by magneto-induction currents being called *magneto bells*. The latter will be described further on in this chapter.

Electric bells are of two kinds—*single stroke* and *trembler*. The former are the simpler, and consist of an electro-magnet, the armature of which has a hammer attached, which strikes on a gong each time a battery is connected to the terminals. The *trembler* bell has, in addition, an arrangement which

automatically breaks the circuit when the armature is attracted. Fig. 77 shows a common and reliable form: A and B are two terminals; A is connected to one end of the magnet coils *a a*, the other end being soldered to the iron frame; B is connected to pillar *b*, which is insulated from the frame by an ebonite bush. Attached to the armature is a spring, *c*, which in its normal position presses against a contact screw in the top of *b*, which contact forms part of the circuit. On sending a current through the coils the armature is attracted, and the spring *c* leaves the contact screw, and breaks the circuit. The armature then falls back, makes contact, and is again attracted, thus giving rise to repeated strokes of the hammer *d* on the gong *e*, as long as the outside circuit is complete to a battery.

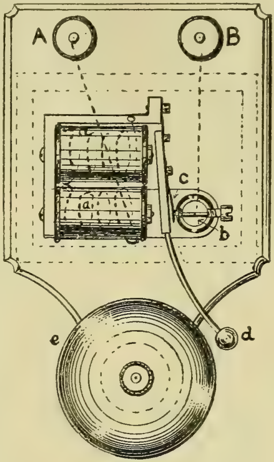


Fig. 77

Fig. 78 shows a useful form of trembler in which the working parts are covered and protected by the dome, thus making a very compact arrangement.

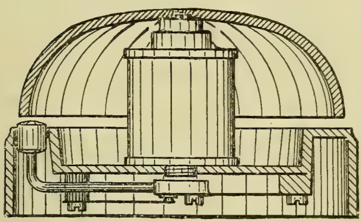
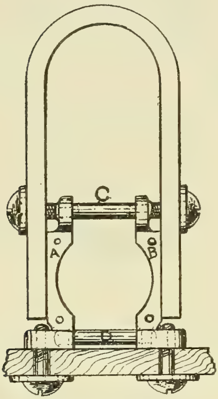


Fig. 78.—Scale $\frac{1}{2}$

Both points of contact between the vibrating spring and the end of screw should be fitted with platinum, as a readily oxidisible metal is burnt away by the sparking which takes place, and faulty contacts may ensue. Other practical points are the same as those given for electro-magnets in Chapter I.

Magneto Switch-Bells.—In the early days of the telephone, batteries were almost exclusively used for signalling purposes, but they were soon superseded by mechanical generators of electricity, based on Faraday's discovery that currents could be generated by the relative movements of coils of wire in the vicinity of magnets. These *magneto switch-bells* have the advantage that they are more self-contained and reliable than those operated by battery, and that they will operate



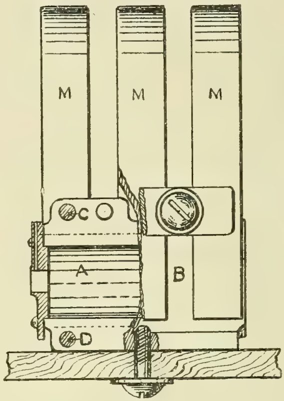


Fig. 79 Scale $\frac{1}{3}$ Fig. 80

through lines of very high resistance, which would require strong batteries if worked by battery power.

Magneto switch-bells consist of four principal parts :

1. The *magneto-generator*, with its driving gear, by means of which the signalling currents are produced.

2. The *automatic cut-out*, an arrangement for short-circuiting the generator coils when the generator is not being used, and sometimes also an additional arrangement for short-circuiting the bell-coils when the magneto-generator is being operated.

3. The *polarised bell*, which is operated by the currents produced by a magneto-generator.

4. The *automatic switch*, as before stated, serves the purpose

of automatically switching the line connection from the ringing to the speaking circuit of the instrument when the receiver is lifted from its rest for speaking purposes.

The *magneto-generator*, or simply the *generator*, usually follows the form of a machine first constructed in 1858 by Dr Werner Siemens, in which a cylindrical armature, which he had just previously invented, was caused to revolve between the poles of a powerful horseshoe magnet.

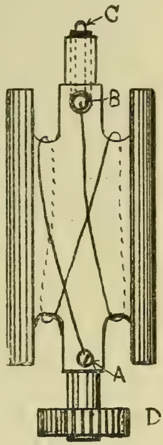


Fig. 81

Figs. 79 and 80 show the magnets of a common form of generator fitted on to cast-iron *pole-pieces*. The pole-pieces are braced together by four brass rods, only two of which, C and D, are shown. The whole is next bored out so as just to allow the Siemens' armature (which is generally about $1\frac{1}{2}$ inches diameter) to revolve freely within. Three or four or in some cases even five, horseshoe magnets are clamped by iron plates and screws to the pole-pieces A and B, so that all their marked ends are on one side. The screws shown at the bottom are for clamping the generator to the base of the containing case.

The *armature* for the machine is made by winding silk-covered copper wire, of about 4 or 5 mils diameter, on a soft-iron core of the shape shown in plan by Fig. 81, and in end view by Fig. 82. This core is a cylinder of iron, out of which has been cut two deep and wide slots, one on each side, leaving only a comparatively thin web and a shaft in the centre, on which it may be made to revolve. As shown in Fig. 81, the web is cut away at each end to allow for the wire, which is wound on longitudinally in the recesses thus formed, the surface of the recesses having been first covered with varnished paper to give better insulation. The

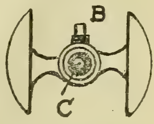


Fig. 82.—Scale $\frac{1}{2}$

wire being wound on until the armature is nearly filled to the circular form and the resistance is about 500 ohms, one end is connected to a small pin, A (Fig. 81), screwed or driven into the metal, and the other end to a pin, B, which is insulated by being embedded in a small ebonite tube, but makes connection with another brass pin, C, also insulated by a vulcanite tube let into the centre of the spindle.

Brass end-pieces are attached by screws to the ends of the magnet pole-pieces. They have bushes at their centres, in which the ends of the armature spindle fit. On the projecting end D of the armature, a small-toothed wheel is fitted, which gears into another toothed wheel about four times its diameter, carried on a shaft which works in bearings connected to the brass end-pieces of the *armature box.* This shaft is driven by a crank handle outside the instrument case, the armature making about five revolutions for each one of the crank.

Mode of Action.—The space between the pole-pieces of the magnets is a powerful magnetic field, in which, when the armature is not in position, the lines of force pass across almost in straight lines from one pole to the other. The coil of wire, in revolving in this field, is continually varying the number of lines of force which pass through it, the number passing through being greatest when the web of the iron core is in a position straight across from pole to pole, and least when it is in a position at right angles to this. When the armature is in the former position nearly all the lines pass through the web of the core, and, therefore, through the centre of the coil; whilst when in a position at right angles to this most of the lines pass through the outer circular segments of the core, none passing through the web joining these. The relative direction in which the lines of force pass *through the coil* is reversed with each half revolution, and, therefore, a complete revolution gives rise to two currents, alternating in direction, if the circuit through the coils is completed.

Another, and perhaps simpler, explanation of the action will be understood by noting the fact that the core of the

armature is converted into a magnet by the lines of force passing through it, and that its polarity is reversed twice in every revolution, each of the reversals inducing a current in the surrounding coil, which is opposite in direction to that produced by the previous polarity.

The faster the armature is revolved the greater the speed of the changes which take place, and the greater is the E.M.F. induced. The latter is also increased in proportion to the number of turns of wire on the armature, the strength of the magnets, and the softness or *permeability* of the iron of which the core is made. In a good form of generator the E.M.F. reaches about 75 to 80 volts at ordinary speeds.

Driving Gear.—Toothed-wheel gearing is usually employed for revolving the generator armature. The teeth of the wheels must be fine and accurately cut by machinery, otherwise they make a disagreeable noise when revolved. It was this noise which prevented toothed gearing coming into general use sooner, many people preferring the usually quiet methods of driving by friction gear or by india-rubber bands and grooved pulleys. The ratio of the number of teeth on the driving wheel to that of the pinion is generally about 5 to 1; but it should not be exactly this ratio, or the wheels are likely to wear unevenly. An odd tooth is usually added to the driving wheel.

Automatic Cut-Outs.—When the generator is not actually in use for ringing, it is important that its resistance, which is considerable, should be cut out of the circuit, since it is useless, and would weaken the signals received on the bells. In order to effect this purpose many ingenious devices have been invented, which are called *automatic cut-outs.* In most cases the force required to turn the armature is utilised to cause the removal of a short circuit of the armature coil, and thus throw its wire into the circuit. Fig. 83 shows an interesting plan for attaining this object, used in the old "Post" instrument. A weight, *e*, on the end of spring *b* flies out by centrifugal force when the armature is revolved, and breaks a short circuit of the armature coil at *c*.

In another form of centrifugal cut-out a metal box fixed to, but insulated from, the armature axis is three-quarters filled with small metal balls like shot. When the armature is at rest these balls short-circuit the armature, but when this is rotated the balls fly to the outer rim of the box, and leave the axis free, and so open the short circuit of the armature.

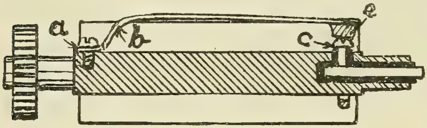


Fig. 83

The *cut-out* shown in Fig. 84 was introduced by the Western Electric Co. It has given much satisfaction, and is, perhaps, the type most frequently used. The driving shaft A runs in bearings cast on the ends of the armature box. E is a toothed wheel, gearing into a smaller one attached to the armature. E is driven by a steel pin passing through the shaft and bearing against the inclined face of a V-shaped recess cut in its boss, F. On attempting to

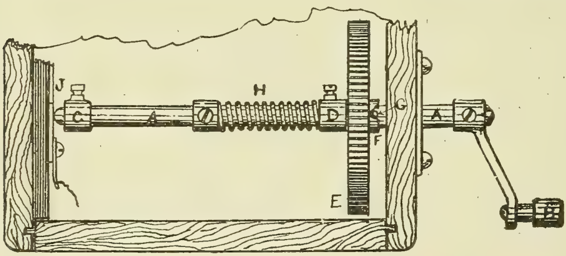


Fig. 84.—Scale $\frac{1}{3}$

turn the crank B, some force is necessary before the armature can be moved, and the result of applying this force is that the pin G moves along the inclined face of the recess, withdrawing the end of the shaft from the spring J, against which it is usually pressed by the spiral spring H. The spring J also presses against the insulated pin at the end

of the armature pivot, to which one end of the coil is attached; and as the other end of the coil is attached to the framework, through the pivots, it is obvious that when the shaft A touches J the coils will be short-circuited, and when drawn away by the act of driving this short circuit will be broken.

The above was the form of cut-out generally used until a few years ago, the polarised bells then being wound to a resistance of about 250 ohms; but as these bells are now wound to a resistance of 1000 ohms, and offer considerable impedance to the generator currents, it is usual to arrange the cut-out so that, in addition to short-circuiting the generator when at rest, it also short-circuits the bell coils when the generator is in use. This is accomplished by making the end of spring J follow the end of shaft A, when the latter is withdrawn by turning, until J comes into contact with a metal piece connected to one end of the bell coils, the other end of the coils being connected to spring J. This is shown in Fig. 85, which shows the cut-out of an Ericsson magneto-generator lettered to correspond with Fig. 84. With this ringer cut-out, the local bell is, of course, silent when the handle is turned; and this is to some extent a disadvantage, as the ring served the subscriber as an indication that the circuit was complete.

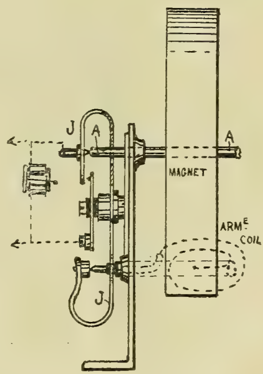
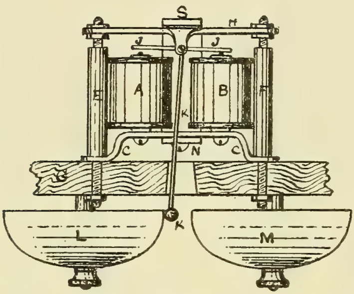


Fig. 85.—Scale ½

Many other forms of automatic cut-out are in use, but the above are probably the most important types.

The Polarised Ringer.—As the currents which work this bell (sometimes called the *ringer*) are produced by a magneto-generator, and follow each other with great rapidity (each turn of the handle generating about ten separate currents, and the handle being turned on an average four times

each second, thus producing forty separate currents per second), it follows that the bell must be very sensitive to respond to each of these pulsations. The speed of turning the handle of the generator also varies greatly with different persons, so that the bell must be able to respond equally well to varying speeds. An ordinary battery bell will only respond satisfactorily to currents following each other at a certain rate, and will, therefore, not be suitable for magneto-generated currents. It has been known for a long period in telegraphy that the instruments which respond best to rapid pulsations of currents are those which are polarised—that is to say, in



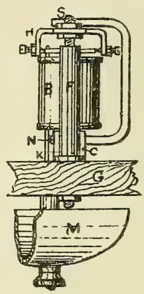


Fig. 86 Scale $\frac{1}{3}$ Fig. 87

which the moving parts are magnetic in themselves, or are maintained in a magnetic state by the induction of magnets. The well-known Siemens' relay is constructed on this principle, and a modification of it was adopted to form the polarised bell.

Figs. 86 and 87 represent a common form of the bell. An electro-magnet formed of bobbins, A and B (wound to a resistance of about 500 ohms each), is screwed to a soft-iron base, C, serving as its yoke. In the centre of C is screwed one pole, N, of a permanent magnet. At the ends of the base C two brass rods, E and F, are screwed, the prolongation of the screws serving to clamp the bell to the instrument case G. E and F are also furnished, at their opposite ends, with screws

and nuts, with which the brass bar H is secured in position, and can be adjusted. In the centre line of H two pivot screws are fixed, on which a soft-iron armature, J, can vibrate about its centre, just in front of the ends of the magnet cores, in which brass pins are fitted to prevent magnetic contact. The hammer K is attached to one side of the armature, and moves with it, striking alternately on the gongs L and M, fixed outside on the front of the case G.

The S pole of the magnet is over the centre of the armature J, and polarises it by induction, the middle being made of north polarity, and the ends of south polarity, whilst the ends of the cores are made of north polarity by the N pole of the magnet.

Action.—The effect of passing a current through the coils is to strengthen the north polarity of one core and to weaken, or altogether neutralise, the north polarity of the other core, the effect being that the armature is strongly attracted to one core and not at all to the other. The next reversal of current causes the core which was strengthened before to be weakened, and *vice versâ*, so that the armature vibrates over to the opposite core, and in doing so causes the hammer to strike on the gongs, and so on repeatedly. Sometimes two polarising magnets are used, one to each core, but the action and effect are similar.

Long-coil Ringers.—Ringers are now often made with the coils nearly double the length shown in Fig. 86. A greater number of turns of a larger gauge of wire being used, the magnetic effect and inductance of the coils are thereby increased; they ring better, and offer much more impedance to the speech waves, which is an advantage when they are connected as shunts to a line, as in party-line working. Fig. 88 is a view of such a *long-coil* ringer.

Ericsson's Ringer.—Fig. 89 gives a view of another form of ringer, in which a flat permanent magnet, N S, is made to serve as the reciprocating armature. The S pole is pivoted in a recess cut in the soft-iron yoke of the coils, and the N pole vibrates between the two pole-pieces, these being rendered

of S polarity by induction. This polarity is strengthened in one and weakened in the other alternately by the ringing

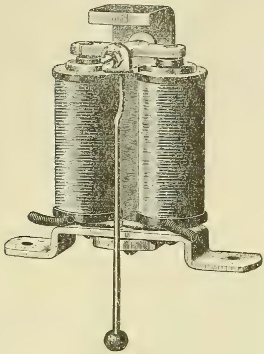


Fig. 88.—Scale $\frac{1}{3}$

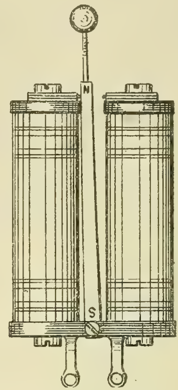


Fig. 89.—Scale $\frac{1}{3}$

currents, so causing the N pole of the magnet to vibrate between the two. Whilst this ringer is generally satisfactory, it has the disadvantage that the magnet armature is liable to lose its strength. For this reason, Messrs Ericsson have recently adopted a ringer having the same general appearance as the above, but which is on the same principle as that of Fig. 86, the soft-iron armature being pivoted on an axis parallel to the cores, and attracted to the sides of the ends of the core, as shown in Fig. 90.

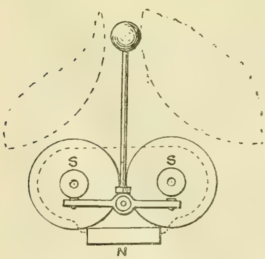


Fig. 90.—Scale $\frac{1}{3}$

A very neat form of ringer is shown in Fig. 91, as made by the Stromberg-Carlson Co. of Chicago. By turning the screw A, which passes freely through the magnet B and armature C, the latter can be very readily adjusted to the proper distance from the core ends, the pivot frame D acting as a flexible spring.

A good generator should give a steady ring on a 1000-ohm ringer when joined through a resistance of 30,000 ohms connected in series or when the ringer is shunted with a 50-ohm shunt.

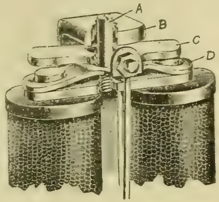


Fig. 91

Automatic Switch.—There are a number of different patterns of these switches, by different makers.

Perhaps the most common, and a very satisfactory form of automatic switch, is that introduced by the Western Electric Co., and shown in Figs. 92 and 93. The strong spring *d* serves both as the bell-contact spring and for throwing up the lever when the receiver is removed, its end bearing on a button of ebonite, *w*, on the lever when the latter is up, and on a metal piece, *x*, when the lever is down. Similarly, the ends of the three springs *a b c*, shown separately in Fig. 93, press on the ebonite piece *y* when the lever is down, and on the contact plate *z* when the lever is up—all the springs changing

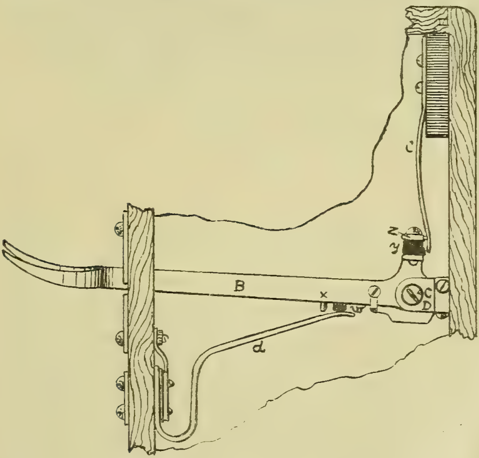


Fig. 92

Scale ½

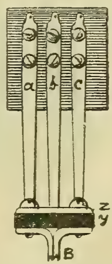


Fig. 93

contact by a kind of rolling motion from metal to insulator, and *vice versâ*. As the lever is long, and the contacts close to the pivot, the leverage is great, the springs can be made strong, and the contacts firm. There is also a small amount of rubbing, which improves the contacts. In a later form of the switch this rubbing is increased by the upper contacts being brought lower down, and farther to the right-hand, as shown in Fig. 114.

Kellogg Switch.—Many of the automatic switches used in

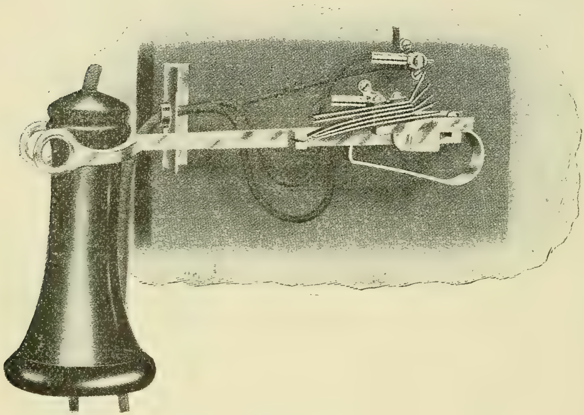


Fig. 94

America are made up in the style of that shown in Fig. 94. As the lever of this moves up or down it carries with it the centre one of five springs, insulated from each other, and all clamped together by two insulated screws. When the lever is down the centre spring presses together the two lower springs, which short-circuits the speaking instruments; and when the lever is up the two top springs are pressed together, so short-circuiting the ringing apparatus.

Cradle Switch.—Fig. 95 shows the form of switch generally used on the National Telephone Co.'s wall sets. It differs considerably from the forms already shown, and is fixed

underneath the desk top, A A, of the instrument. It consists of two levers, B and C, pivoted at D and F, these pivots, being provided with safety spirals to ensure good contact. F is the lower part of the stem of the cradle on which the hand-micro-telephone rests when not in use, G being an ebonite bush which acts as guide and support, and H an insulating button. The weight of the hand-micro-telephone depresses the ends of the levers B and C against the tension of the springs S S, and the outer ends make contact with the springs J and K, the contact at L being at the same time broken. The tension of the springs S S can be altered by the adjuster M,

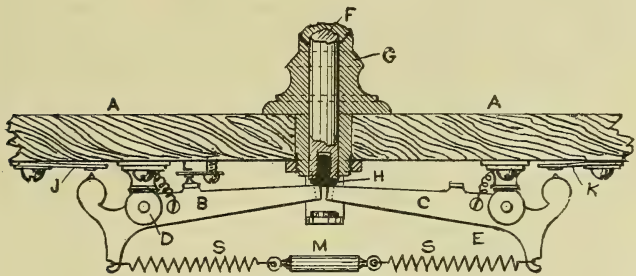


Fig. 95.—Scale ½

furnished with right and left handed screws. The full connections of this switch are shown in Fig. 116.

Hand-Micro-Telephone.—This is a standard form of combined transmitter and receiver now in use in this country. Owing to its great convenience it has become very popular, although, strange to say, it is but little used in America. It combines the two instruments in the most convenient relative positions, and allows the user to adopt any convenient position. Constructed of ebonite and aluminium, it is but little heavier than an ordinary double-pole receiver. The instrument is generally fitted with a cut-off key for the transmitter battery, so as to render it independent of the ordinary automatic switch-hook or cradle spring. Fig. 96 shows one

of these instruments, usually called H.M.T.'s. The contact spring is fitted on the front of the handle ; it is attached to a projecting ebonite strip, which, when grasped by the hand, is pressed inward, and so makes the necessary battery contact for the microphone.

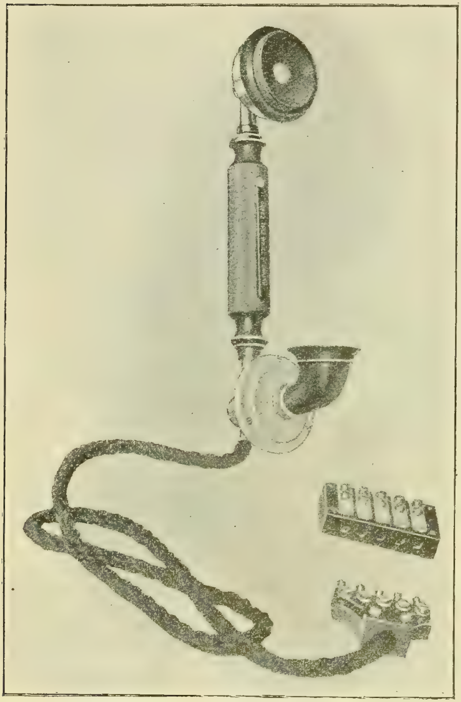


Fig. 96

Instrument Plugs and Jacks.—The figure also shows a 5-strand connecting cord attached and fitted with a 5-point instrument plug. The latter is made up of five metal plugs fitted in an ebonite block, and so arranged that they may be all inserted at once into a 5-point *instrument jack.* As will be seen, this is an ebonite block fitted with five springs, on the free ends of which are fitted metal studs. These studs project into holes drilled in the ebonite block, in which the plugs are inserted. Contact is thus effected between plugs and springs. The 5-point plugs and jacks are only required when a connection has to be made to the centre of the receiver coils. In ordinary circumstances 4-point plugs and jacks, as shown in Figs. 97 and 98, suffice.

Two-way switches are often required for the purpose of breaking a circuit or to change on to different apparatus. Figs. 99 and 100 show a good form. The handle is attached

to the centre of a brass spring A A, one end of which bears on the piece B, and the other end on one of the brass pieces C or D, according to the direction in which the handle is

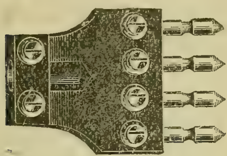


Fig. 97.—Scale $\frac{1}{2}$

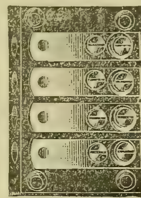


Fig. 98.—Scale $\frac{1}{2}$

turned. Similar switches are made, as 3, 4, 5, 6, etc., point switches for special purposes, having a moving arm which swings round on a centre so as to make contact with the various studs.

Lightning Arresters and High-Voltage Guards.—As the bell, armature of generator, receiver and induction coils are wound with fine wire to a high resistance, such coils are especially

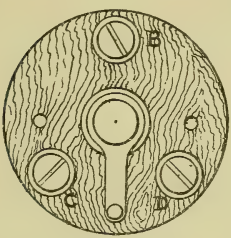


Fig. 99 Scale $\frac{1}{2}$ Fig. 100

liable to damage by lightning, as a moving charge of electricity has a property similar to the inertia of a moving body, tending to move in a straight line, and not deviate, which a charge has to do when passing through the turns of a coil. A lightning charge will, when the conditions of the circuit are favourable, spark across a comparatively great thickness of an insulator rather than pass through many turns of wire; all

instruments should, therefore, be provided with some form of protector, in which a short and favourable spark gap—usually through air—is arranged. Otherwise the charge will be liable to spark across the silk covering of the wire on the coils, and in so doing fuse the wire itself.

A common form of protector is one in which two metal

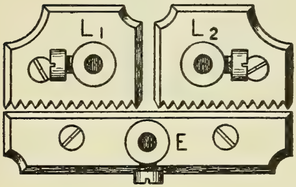


Fig. 101.—Scale $\frac{2}{3}$

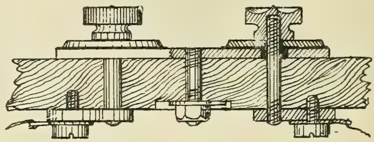


Fig. 102.—Scale $\frac{1}{2}$

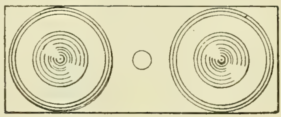


Fig. 103.—Scale $\frac{1}{2}$

plates, with saw teeth connected to the two-line terminals, are fixed close to, but not touching, a metal plate having a good earth connection, as shown in Fig. 101. If this form is well made, with the teeth milled so as to be sharp pointed and these teeth are adjusted to within about 4 mils of the earth plate, it will prove a very effective safeguard. In the rough state in which it is often found, however, it is of very little value.

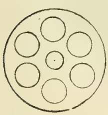


Fig. 104
Scale $\frac{1}{2}$

The form of protector used on the wall sets of the National Telephone Co. is shown in Figs. 102 and 103. Two terminals, A and B, each clamp a metal washer, which is kept from contact with a metal earth-connected plate, C, by a mica washer of somewhat larger diameter, and about 5 mils in thickness. The mica is perforated with a number of small holes, as seen in Fig 104, to provide

an air gap. The screwed stems of the terminals are insulated from the earth plate by ebonite bushes.

Sometimes a lightning arrester takes the form of a single layer of wire, with a thin silk covering, wound on a metallic bobbin which is connected to earth; or two or three thinly-covered wires may be twisted together, and wound on an insulating bobbin, one of the wires being connected to earth and the other to the line wires. If the lines become charged to a high potential they spark through the silk covering to the earth-connected wire or bobbin.

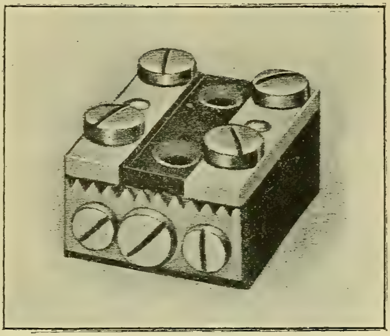


Fig. 105

Owing to metallic circuit lines having no direct connection with earth, they are especially liable to damage by lightning, so that with such lines, in addition to the arresters forming part of the instruments, it is usual to provide other safety devices, both at the exchange end of the line and at the point at which the line wires enter the sub-station. These are made in the form of *window terminals*, serving also to terminate the outer line wires. Fig 105 shows a common form, in which the earth plate of the arrester is of the saw-tooth form, adjusted to the two brass-line terminal plates. It is necessary to provide a good earth connection.

Special Protection.—Where the lines are in the least likely to come into the neighbourhood of heavy-current supply lines, which are now very common, safety devices of a more elaborate nature are necessary to obviate the possibility of trouble resulting from an accidental contact with the current supply wires.

Such contact may be (*a*) of somewhat high resistance, but

affording passage to a current of a strength which, if continued for a few minutes, will raise the temperature of thin copper wire—such as that of bell coils, etc.—until it is hot enough to ignite surrounding materials. These are called *sneak currents* in America, and are guarded against by providing special thin wire coils of German silver wire, and utilising the heat developed by the current to fuse a portion of easily fusible metal, this releasing a spring which breaks the circuit.

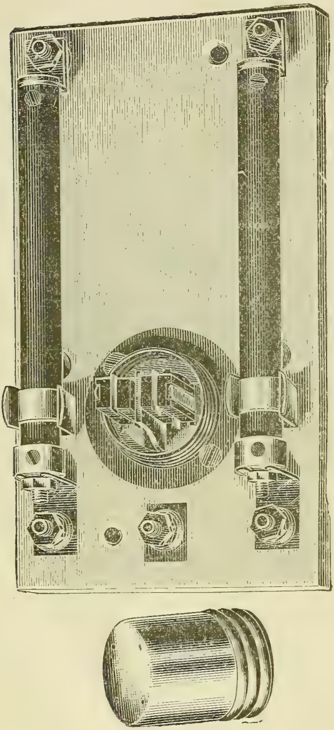


Fig. 103.—Scale $\frac{1}{2}$

Or (*b*) the contact may be of low resistance, and the current may more likely be of a strong and dangerous nature. For such risks a fusible metal wire, which immediately fuses when the current is from $2\frac{1}{2}$ to 3 amperes, is inserted in the circuit.

Another case is (*c*) where the potential of the line may be raised to sparking point; but very little current is produced, both wires being at a nearly equal potential, in which case the spark to other conductors may give rise to a fire. To guard against this risk, an easy sparking device is arranged, generally between two blocks of carbon, the heat generated by the sparking fusing a drop of fusible metal, which falls to a lower position, and short-circuits the carbon blocks, thus providing an easy path to earth, and afterwards causing the sneak current device, and perhaps the wire fuse, to operate.

Terminal Block.—To meet the requirements mentioned above, the terminal block shown in Fig. 106 is used. This combines a safety guard for each of the cases mentioned.

The lightning arrester consists of two carbon blocks separated by a piece of mica, of the shape shown in Fig. 107, and about 5 mils in thickness, which must always be placed with the opening downwards, as shown, to prevent dust accumulating between the carbon blocks. One of these blocks has a

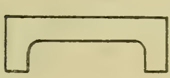


Fig. 107.—Scale $\frac{1}{2}$

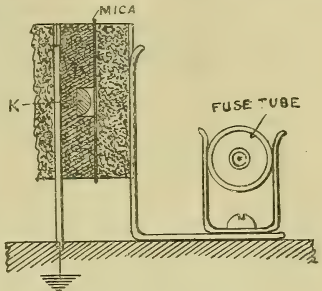


Fig. 108.—Scale $\frac{1}{2}$

globule of easily fusible metal in the centre, as shown at K in Fig. 108 (which is a sectional view of one side of the terminal block), which, with prolonged sparking, due to contact with high-tension-current systems or lightning, melts, and joins the two blocks together, thereby earthing the line, and melting a fuse. This fuse is a strip of soft metal, F,

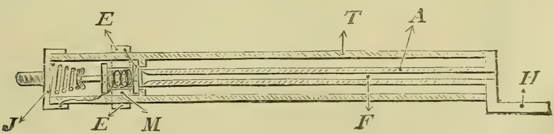


Fig. 109.—Scale $\frac{1}{2}$

Fig. 109, surrounded by asbestos, and enclosed in a fibre tube, A. It melts instantly with a current of $2\frac{1}{2}$ to 3 amperes.

The heat coil R of Fig. 109 is of 43 ohms resistance, and is wound on a metal bobbin, M, which is joined by means of fusible solder, L, to a metal stud, Q, connected to the fuse F. Any current of more than $\frac{1}{3}$ of an ampere, passing through

the coil for sufficient time, heats the bobbin, and melts the solder, when the stud is pushed away by a glass rod, V, actuated by a spiral spring, S, so breaking the connection. The coil pro-

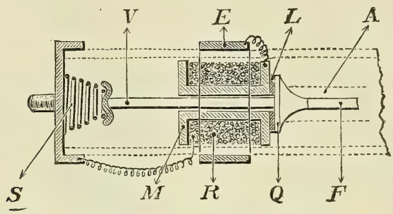


Fig. 110.—Full size

tects the apparatus from small currents of considerable duration. Fig. 109 gives a section of the fuse tube, and Fig. 110 an enlarged section of the lower part.

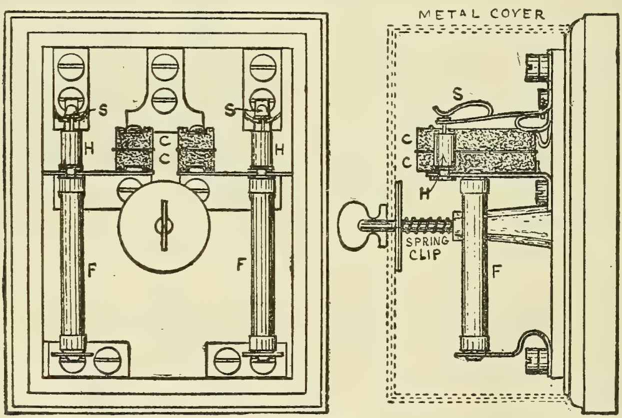


Fig. 110*a* Scale ½ Fig. 110*b*
Ericsson Instrument Protector

Figs. 110*a* and 110*b* show the Ericsson form of instrument protector which is now extensively used. The heat coils H and fuses F are separate and the former are so arranged that when the fusible metal melts the spring clips S S fly open and introduce a gap in the circuit.

See Chapter XXI. for other forms of protectors.

CHAPTER VII

SUB-STATION INSTRUMENT CONNECTIONS

Instrument Connections.—There are two general methods of joining up the various parts of a magneto or other switch-bell—(*a*) the *series* method, and (*b*) the *shunt* or *short-circuiting* method. For a long time the series method was almost universally employed, but the shunt system is now most generally used. Fig. 111 gives the connections of a magneto bell on the series plan, and Fig. 112 the same parts joined up

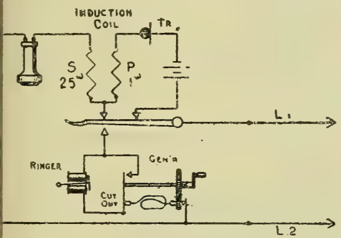


Fig. 111

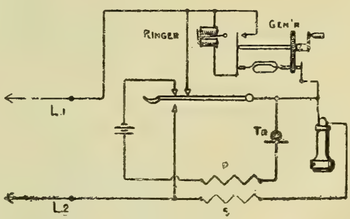


Fig. 112

on the shunt method. In the first the movement of the switch-hook, after taking the receiver off, connects up the speaking circuit, and completely breaks off the ringing circuit; while in Fig. 112 the same movement does not break either circuit, but simply short-circuits the ringing part of the instrument, and opens a short-circuiting contact which existed in the speaking circuit. The latter method has the advantage that, if a break should occur at the switch-hook contact in either circuit, the instrument can still be used, the ringing and speaking currents then passing through the whole of the apparatus.

Fig. 113 gives the connections of the shunt form of magneto

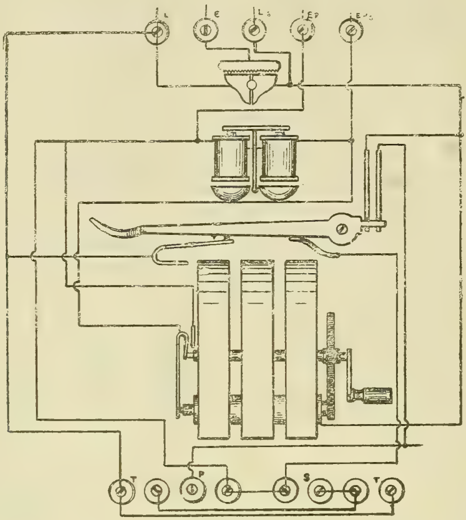


Fig. 113

bell, showing the various parts in their relative positions.

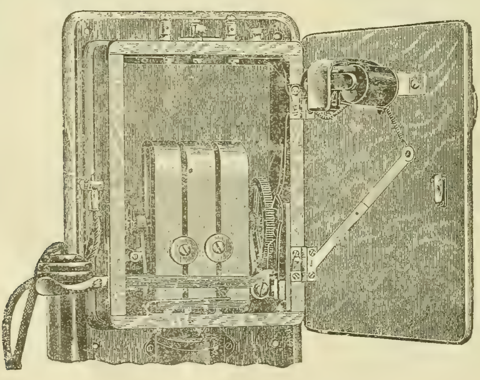


Fig. 114

Between the two pairs of terminals at the bottom, marked

T T, one or two receivers may be connected; if the latter they will be connected in parallel. Between the P pair the primary circuit of the transmitter is connected—one to one end of the induction coil, and the other to one pole of the transmitter battery. To those marked S, the secondary ends of the induction coil are connected. The upper terminals are, from

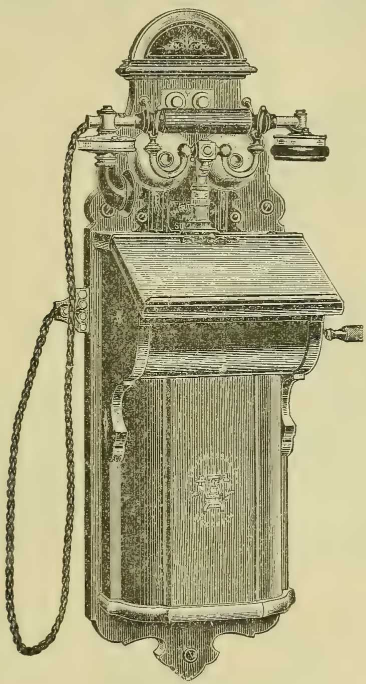


Fig. 115

the left, No. 1 Line, Earth, No. 2 Line, and Extension Bell wires Nos. 1 and 2. The two latter terminals are for connecting an extra bell, to be rung in some other part of the building. It is connected (if required) as a shunt to the instrument bell, a 2-way switch being often used in conjunction, so that the extension bell may be cut out when not required to

ring. A drop indicator, of the same resistance, may be used in place of the bell. Fig. 114 shows the general appearance of the inside of this form of instrument.

Standard Pattern Wall Set.—Fig. 115 gives a general view

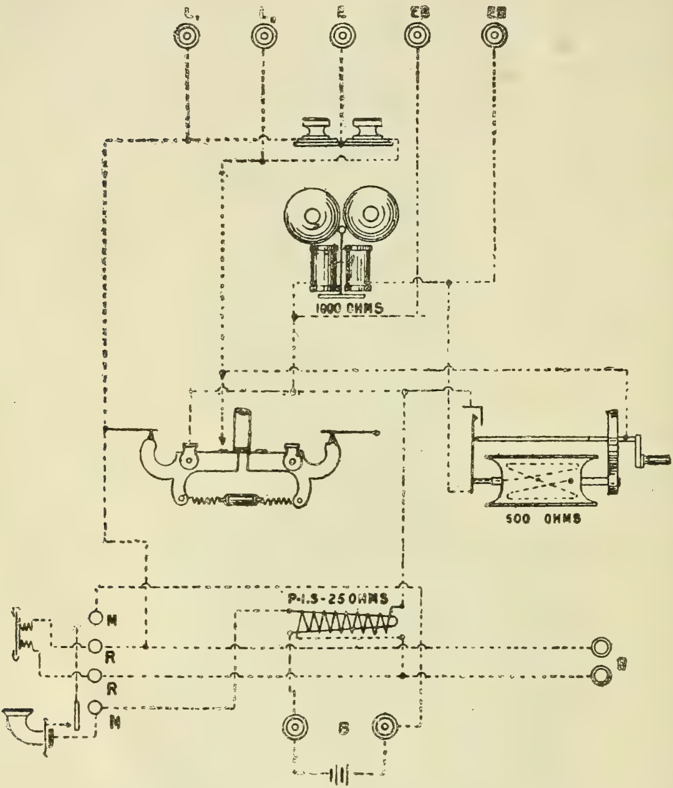


Fig. 116

of the National Telephone Co.'s form of wall-pattern instrument, and Fig. 116 gives the connections of the same, which, it will be observed, are similar to those of Fig. 113, except that a hand-micro-telephone is used,

Table Sets.—Fig. 117 shows a very popular form of table or desk instrument made by the Ericsson Co. of Stockholm. This firm is much to be commended as having introduced into this country instruments which combine a considerable amount of artistic taste in design with very high-class workmanship. As will be seen, two generator magnets are used as supports for the whole instrument. The induction coil is contained in the pedestal through which the stem of the

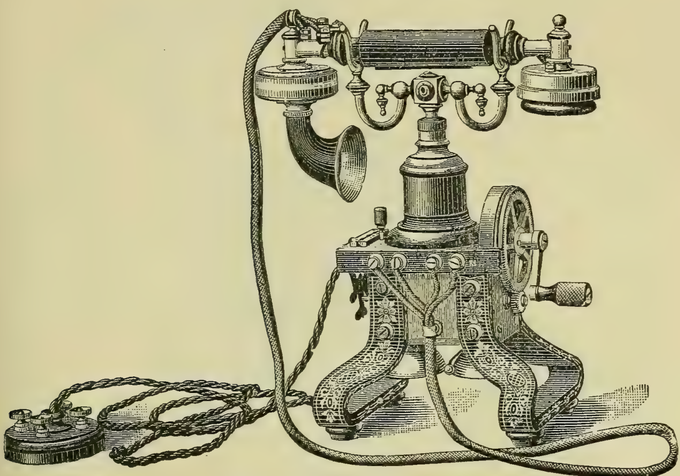


Fig. 117

two-pronged cradle switch passes. The connections are shown in Fig. 118, this also showing the centre point of the bell coils connected to earth. If this connection is not required for special signalling, it is omitted.

Many of the parts of the above class of instrument are nickel-plated, and, being exposed to dust and damp, much trouble is experienced in our climate in keeping them clean. For this reason a form of table set has been recently intro-

duced of a somewhat similar design, but in which all the parts, with the exception of the cradle switch and generator handle, are protected under a highly-decorated japanned metal cover. Fig. 119 is a view of an instrument of this class, which was first used by the Glasgow and other corporations, the arms of that city being emblazoned on the sides of the cover. A

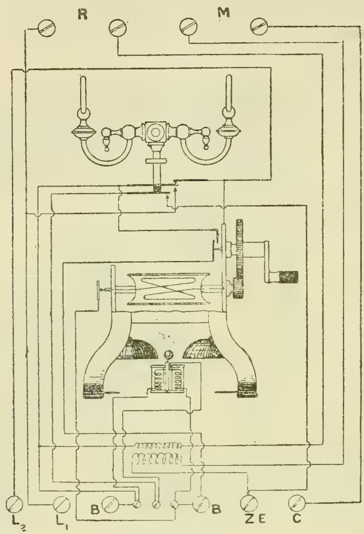


Fig. 118

similar kind of instrument is now used by the National Telephone Co.

The Battery Switch-Bell.—For short private lines, and for telephones between different parts of the same building, signalling is often done by means of batteries instead of by magneto-generators, an ordinary trembler electric bell being then used for calling attention. Fig. 120 gives a view of a wall-pattern instrument of this class. The connections are made both on the series system and on the shunt system, as with magneto switch-bells. Part of the ringing battery

(which for lines under $1\frac{1}{2}$ miles in length need not exceed four cells) is used for the microphone battery. As one end of the ringing battery is joined to earth or to return wire it is necessary to insulate the primary circuit from direct contact with the switch-hook and to use an independent contact for closing the primary circuit of the microphone, otherwise part of the current would be working through the line wires. A contact for the

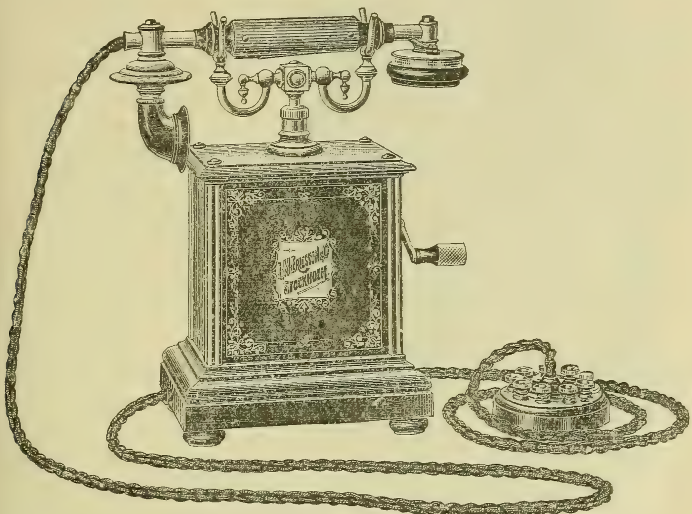


Fig. 119

purpose is, therefore, provided on an insulated conductor attached to or moved by the switch-hook when a hand-micro-telephone is not used. To close the battery circuit for ringing the distant station a push button, or lever key, is used, connected to one of the line wires, and provided with a back contact.

The connections of such an instrument on the "series" system are shown in Fig. 121, and on the shunt system in Fig. 122. If an earth return is used instead of a second-line wire,

the terminals L 2 are connected to earth as indicated in dotted lines.

A different type of battery wall instrument is shown in Fig. 123, this being fitted with a cradle switch and hand-micro-telephone, also with a 4-point instrument plug and jack, by means of which the H.M.T. can be readily disconnected.

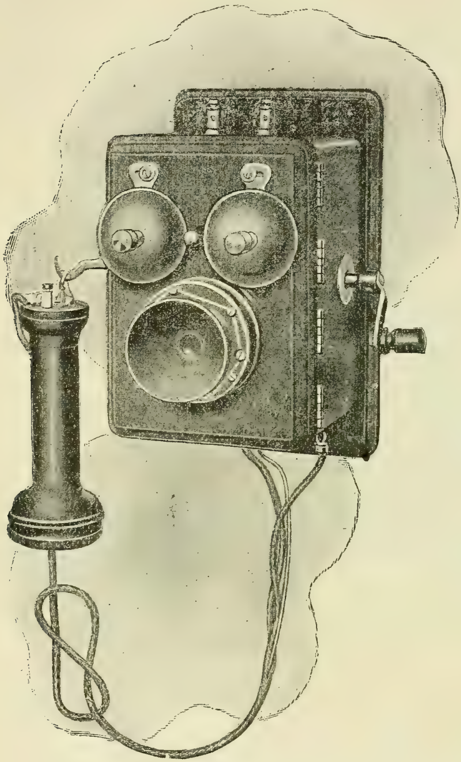


Fig. 120

Fig. 124 shows a table set for battery working as made by Messrs Ericsson & Co. The connections are shown in Fig. 125, in which the loop line, or line-and-earth terminals, are shown on the extreme right. The instrument is connected up on the shunt system, the cradle spring short-circuiting the speaking circuit when the cradle is pressed down, and short-circuiting the bell when the H.M.T. is lifted. The transmitter is worked by the two cells on the earthed end of the battery. The connections of the wall set Fig. 123 are similar to Fig 125.

Central Energy Instruments.—For the common battery

or central energy system of working, which has now become the standard method for exchanges, the sub-station instruments are of a somewhat simpler character, as the generator

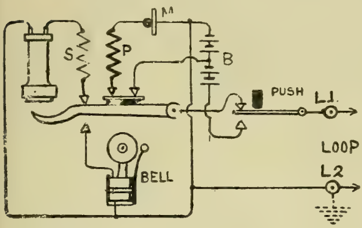


Fig. 121

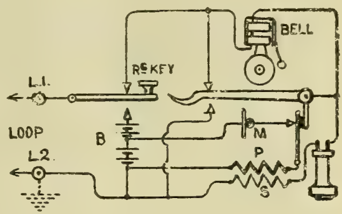


Fig. 122

and the transmitter battery are both dispensed with, and sometimes also the induction coil. This reduction is, however, partly counterbalanced by the addition of a condenser.

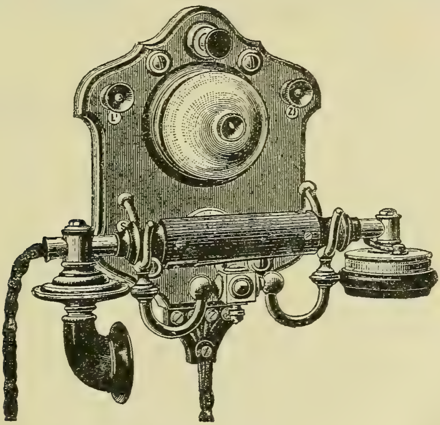


Fig. 123

Fig. 126 shows the connections of the simplest form of C.B. instrument, from which it will be seen that when the receiver is on its rest the loop is connected to the ringer, but with a condenser interposed, so that the circuit is really incomplete so far as a direct current is concerned. Although the circuit

is thus incomplete, a polarised ringer can be operated through the condenser, the energy of an alternating current being transferred through the insulating sheets of the condenser.

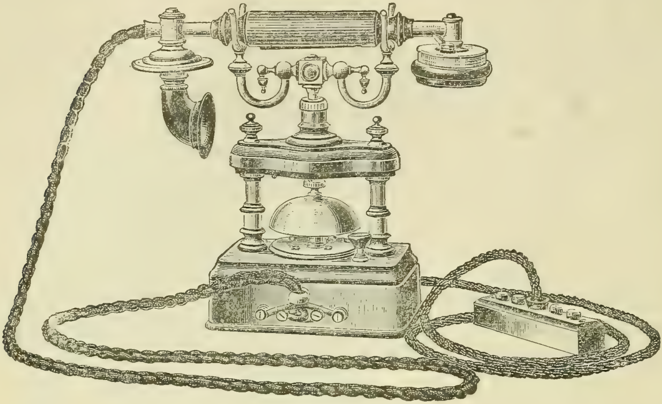


Fig. 124

It is necessary that the latter be of a fairly high capacity, one of 2 to 2·5 microfarads being generally employed.

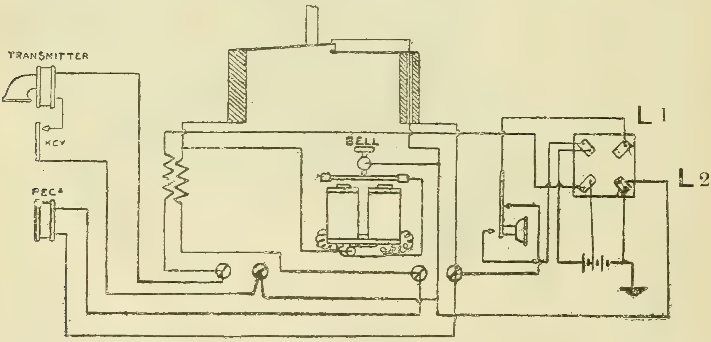


Fig. 125

When the receiver is taken off its support, the loop is completed through the transmitter and receiver, the current for working being supplied from a constant source at the central

office (or C.O.). For speaking purposes, however, this method is not very satisfactory, as the variations caused by the transmitter are choked by the impedance of the receiver. Sometimes the receiver is connected as a shunt to the transmitter, but in this case the receiving suffers, as the speaking currents from the distant end pass in great part through the transmitter, the latter offering very little impedance.

Automatic Signalling.—The instruments arranged as in Fig. 126, combined with a central battery, enable an automatic-signalling system to be adopted. To attain this object, the battery is connected permanently at the C.O. between the two wires of the loop, through an annunciator, or a relay

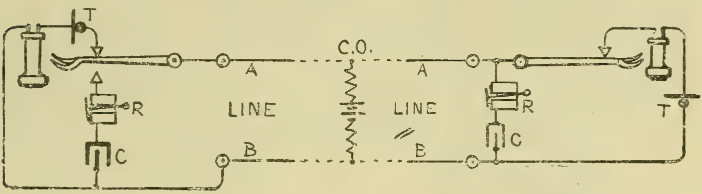


Fig. 126 Fig. 127

arranged for working an annunciator, the latter being usually a small electric lamp. When the receiver is lifted from its support the loop circuit is closed, the current passes, and the annunciator at the C.O. is operated. When the switch-hook is down the circuit is broken by the condenser. Instead of using a condenser, the ringer may be wound to a very high resistance, say 5000 ohms, high enough to keep the current strength below the point at which it would operate the relay or annunciator. When the receiver is lifted the resistance is reduced, and the relay operates. The latter, however, is not a satisfactory plan, as in a large exchange the leakage of the current through the ringer coils would become a serious item of expense.

The ringer with the condenser may be left permanently connected to the loop, as the impedance of the bell coils may be made so great as to prevent leakage of the speaking

currents. This is shown in Fig. 127, no bottom contact to the hooks being then needed.

Many different sub-station circuits have been devised, in order to get the best results in regard to speaking from C.B. working. A few of the most important will now be given in outline.

The first development in the design of C.B. sub-station circuits was in the use of an induction coil, including the primary winding and the microphone in the main-loop circuit, and the receiver and secondary in a local circuit, as shown in Fig. 128. This arrangement is used by several of the inde-

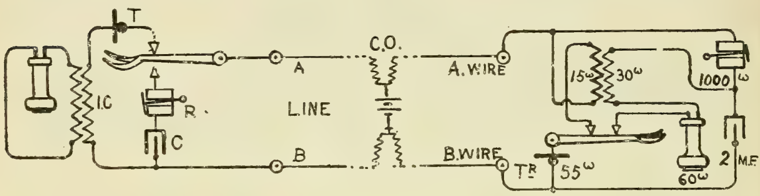


Fig. 128 Fig. 129

pendent companies in America, including the Stromberg-Carlson Co.

The Western Electric Co.'s System.—This system, which is probably the one most extensively used, is shown in Fig. 129. It is employed in this country in several of the National Telephone Co.'s exchanges, and by the Post Office, and also by the Bell Telephone Companies to a very large extent in America, with very good results. As in the last system described, an induction coil is used, the primary and microphone being in the main-loop circuit when the switch-hook is up. The receiver is in the secondary circuit with the condenser (2 microfarads), the microphone, it will be seen, being included in both circuits. When the transmitter is used the two circuits (primary and secondary) reinforce each other. Although there is another direct path for the current through the secondary, the receiver, and the ringer coils, it is, for the

rapidly-varying speaking currents, almost equivalent to a break owing to its very high impedance.

The resistance of the primary of the induction coil is 15 ohms and of the secondary 30 ohms. (Sometimes the former coil is called the secondary, and the latter primary.) The receiver is wound to 60 ohms, and the normal resistance of the solid-back transmitter is about 55 ohms.

A system shown in Fig. 130 is somewhat similar to the Western Electric Co.'s, but it will be seen that the microphone, the receiver, and the secondary coil are in the direct-line circuit, and the microphone and primary and a condenser are also in a local circuit. The transmitter variations cause corresponding variations of potential which affect the condenser, thus giving rise to alternations of current in the primary coil — the two circuits reinforcing each other as in the Western Electric Co.'s system, but the fluctuations in the microphonic circuit being local.

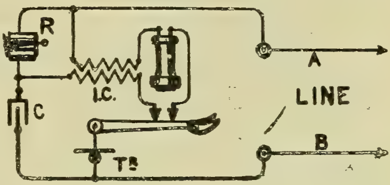


Fig. 130

The Siemen's System.—In this system, which is extensively used in Germany, the fluctuations in the microphone circuit are also localised as in the last system, but in a different manner. Fig. 131 shows the simplest form of the speaking circuit without the switch-hook and bell. The loop has two branches, in one of which is the receiver R, the secondary of an induction coil S, and the condenser C, and in the other branch is a retardation coil, T, the microphone M and primary coil P being arranged as shunts to each other. The retardation coil T prevents the undulations passing direct to line, and confines them to the local primary coil circuit. In a later form of this system the ringer coils are used in place of the special retardation coil, and a condenser is included in the primary local circuit, as shown in Fig. 132.

Electrolytic Cell.—In place of the condensers shown in Fig.

131, Messrs Siemen sometimes make use of what are called *electrolytic* or *polarisation* cells. These are merely small, sealed glass bulbs nearly filled with a solution of an electrolyte such as ammonium phosphate, and having connecting

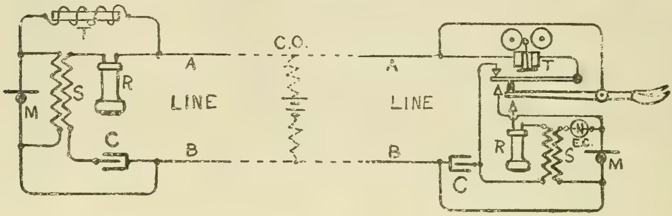


Fig. 131 Fig. 132

wires of platinum cemented through the glass, and soldered to two small aluminium electrodes, as shown in Fig. 133. Like condensers, these cells have the property of allowing the apparently free passage of rapidly alternating currents but of completely stopping any direct current. An aluminium plate in certain solutions has the peculiar property of allow-

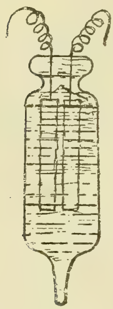


Fig. 133.—Full Size

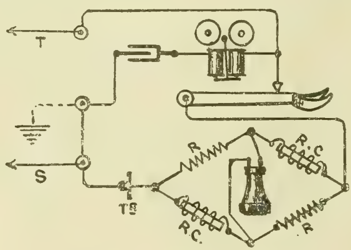


Fig. 133*a*

ing a current to flow in one direction only, namely—from the solution to the plate. With two aluminium electrodes the current is completely blocked. The electrolytic action causes the deposit on the plates of a very thin (about ·00005 inch) insulating film. The plates and surface of the electrolyte

form the plates of a condenser, separated only by the very thin films, and this close proximity gives a very large capacity in proportion to the area of the plates.

The "W. W. Dean" System.—Fig. 133*a* represents an interesting substation circuit used in America. The receiver, it will be seen, is connected as the bridge to four resistances joined like those of a Wheatstone bridge (for which see Chapter XXVIII.). Two of the resistances are non-inductive, and two are retardation coils, which stop the rapid-speaking currents, so that these pass through the receiver and the non-inductive resistances. The steady feeding current from the central battery passes equally through the two paths open to it and none through the receiver if all the resistances are equal.

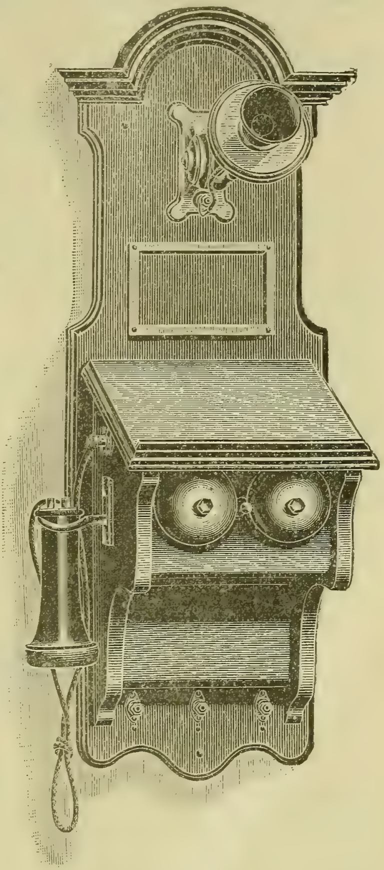


Fig. 134

Common Battery Wall Sets.—The type of subscribers' instrument most generally used for C.B. exchanges is shownin Fig. 134. The transmitter is of the "solid-back" form, as this is found to give the best results with C.B. working. It is fitted at the end of a hinged arm with a second hinge, so that it may be adjusted for height,

and at the same time be kept nearly vertical, which is the best position for working. Fig. 135 gives the connections of the Western Electric Co.'s "standard" type.

Table Set.—The most common form of C.B. table set is that shown in Fig. 136. The transmitter, also a "solid-back," is hinged at the top to a vertical rod, which can be pulled out about $1\frac{1}{2}$ inches for adjustment of height. The automatic switch is of a very simple pattern, the prong lever being attached to a

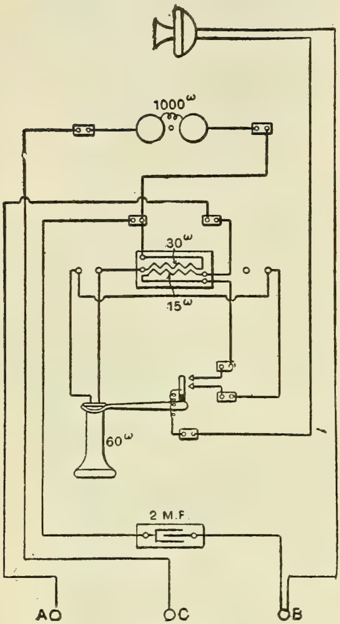


Fig. 135

Fig. 136

horizontal metal ring pivoted on a diameter at right angles to the lever. When the receiver is lifted, a spiral spring under the ring forces up the lever and one side of the ring, and two contact points on the far side of the ring are brought into contact with two insulated springs. The base of the instrument is weighted with lead, and should be broad, to render the instrument more firm.

The table set is unprovided with ringer, induction coil, or

condenser. These are fitted in a separate case—as shown in Fig. 137—which is connected by flexible conductors to the table instrument, and is screwed to the wall or under the desk.

The connections of the complete instrument are shown in Fig. 138.

Instrument-Fixing.—Many practical points need to be attended to in fixing or fitting up the instruments, a few of which will be briefly mentioned.

Position of Instruments.—A position should be chosen which will be as quiet as possible, on a solid wall not subject to vibration, and one on which a good light falls. Care should also be taken that space is left for the user to hold the receiver to his ear, without his arm or the receiver coming into contact with a side wall or other object. If a fixed transmitter is used, the height should be regulated so that the transmitter funnel will be on a level with the mouth of the shortest person who has to use it, as it is easy for a tall person to stoop, but very inconvenient for a short person to stretch up. In

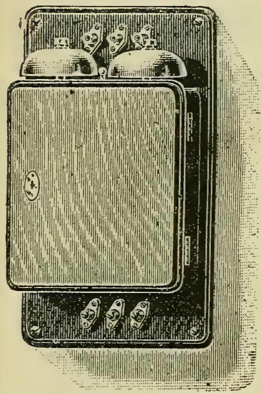


Fig. 137

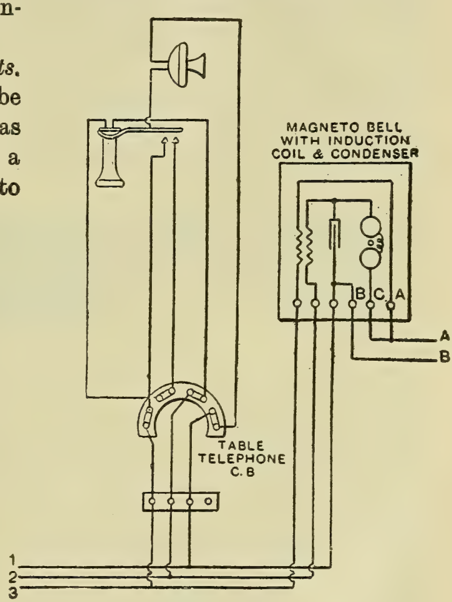


Fig. 138

speaking, the face is naturally inclined downwards. Of course, some of these points are not so important where a hand-micro or adjustable-transmitter arm is used.

If the above conditions cannot be obtained, and a noisy position has to be chosen, a second receiver should be used to exclude the noise, or a "silence" cabinet constructed in which to place the instrument. If the wall vibrates it will give rise to noise in the transmitter, unless the latter is isolated by being suspended on flexible springs of some kind.

Having marked the position of the fixing screws (inquiry having previously been made as to the position of buried gas pipes), plug-holes are made in the wall, and well-dried wooden plugs of about 3 inches in length are tightly driven

Fig. 139

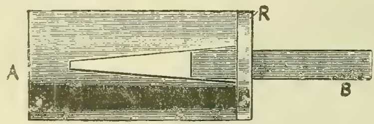


Fig. 140.—Scale $\frac{2}{3}$

in; to these plugs the back board of the instrument is screwed. The plugs may be of a round or square section of about 1 inch diameter or side of square. If of the latter section, the holding power is much increased by cutting the plug a little on the twist, as shown in an end view in Fig. 139, a square hole being, of course, made in the wail. Round holes are, however, much the easier to drill, and a form of plug which gives a very firm hold is shown in Fig. 140. After the plug is inserted in the hole the separate piece B is inserted in the V-shaped slit, and driven home. This causes the inner end A to split and expand, the iron ring R preventing the front end from splitting. Fig. 141 shows the form of ring-section chisel used in making the hole, this being continually turned as it is hammered in. Care must be taken not to damage the wall by too great force being used when hammering in the plug.

The wires are next connected up to the proper terminals,

copper wire, braided with cotton and paraffined, and of about No. 20 gauge, or 36 mils diameter, being used, if the room in which they are fixed is thoroughly dry. If the dryness is at all doubtful, wire having a covering of india-rubber, with an outer braided covering of cotton, should be used. In this case the copper wire should be tinned, to prevent the corroding action on the copper of the sulphur in the rubber.

In stapling the wires care must be taken that the covering is not damaged. Tinned steel staples of a U shape, and about $\frac{5}{8}$ inch in length, are used. If more than one wire is secured under the same staple (which is seldom advisable), special precautions, such as putting a slip of leather or fibre under the staple, should be taken to prevent damage. Care

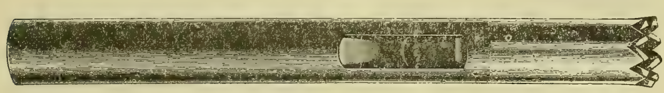


Fig. 141.—Scale $\frac{1}{2}$

should be taken that staples used for adjacent wires should not come into contact.

If a battery is used, a cool place somewhere out of sight should be chosen for it, a cellar being often selected.

All joints in the wires must be soldered. This is best done by using resin as a flux; but a very good soldering solution, suitable for all soldering purposes, may be made up of the following ingredients :—1 pint of methylated spirits, 2 ounces of glycerine, and 3 ounces of chloride of zinc. *Tube solder* is now often used, and is very convenient. The solder is made in the form of a tube of ·08 inch diameter, the small hole through it being filled with resin or some other safe flux.

The instrument should have been previously set up, and thoroughly tested, before leaving the workshop or test-room.

The earth connection for the instrument should be made with a thick copper wire well soldered on to a *main* water pipe. If such water-pipe cannot be obtained, an earth plate

of galvanised iron, about 2 feet square, should be buried in damp ground, and the earth wire connected.

An earth connector which is much used in America is shown in Fig. 141*a*. A tinned copper band is tucked round one side of the brass cradle, passed through the other side, then round the pipe and again through the two slots. The clamping screw is then tightened on to the bands, and the nut and washer is used to clamp the connecting wire. A second nut on the screw, to serve as a lock nut, would be an improvement.

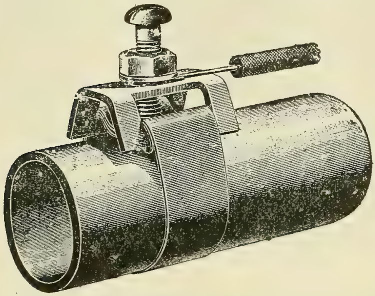


Fig. 141*a*

The type of earth connector adopted by the National Telephone Co. is shown in Fig. 141*b*, which gives two views. After eight complete turns have been made round the combination by the earth wire the latter is tightened on to the pipe by means of the two screws.

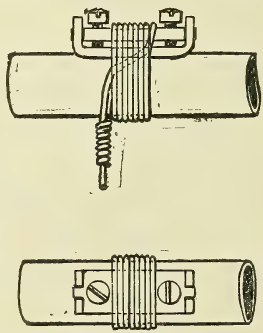


Fig. 141*b*.—Earth-Wire Clamp. N. T. Co.'s pattern

Tools required.—The tools necessary for fixing are: Cutting pliers, long-nose pliers, large and small screw-drivers, gimlets, bradawls, plugging chisel, large and small hammer, 2-foot rule, bell-hanger's augur, tenon saw, and soldering iron.

In addition to above, a joiner's chisel, detector galvanometer, and a pair of tweezers will often prove useful. It is advisable that the small tools should be mounted on a slip of leather, such as used by joiners. This can be rolled up. It will protect the tools, and a glance will show if all the tools are collected.

CHAPTER VIII

INTERMEDIATE SWITCHES AND EXTENSION INSTRUMENTS

The simplest form of a telephone installation is a line having a telephone set connected at each end, as in Fig. 142. Next to this in simplicity is that of three telephone sets connected to the same line—one set at each end, and another one connected at some intermediate point, as in Fig. 143, the instrument being connected as a shunt across the metallic

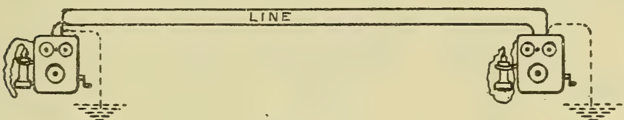


Fig. 142

circuit line. With such an arrangement, when any one station rings, the other two stations' bells will be rung, and it will be necessary to arrange a code of signals of one, two, or three rings for the different stations. More than three stations may be connected to the same line, or to branches

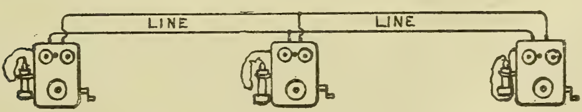


Fig. 143

from this line, and rung in the same manner; and it has been found practicable to have as many as twenty or even thirty instruments joined up in "bridge," code signals of a combination of long and short rings being used for calling the

various stations. Fig. 144 shows ten stations joined up to a branched line. It will be evident that, with such an arrangement, any one of the stations will be able, if desired, to listen to the conversation of any of the others, so that no privacy can be obtained, and the amount of ringing at every station must be very trying. Such arrangements are often used in country districts, which cannot afford the services of a constant operator or of separate lines.

The instruments used for such a system should be of special type, supplied with generators having powerful magnets, and large armatures wound with a large number of turns to about 350 ohms, so that the current strength as well as the voltage may be great, as the current will have to split up among all the instruments on the line. Also, as the bells of all except those on the two speaking instruments will be connected to line as shunts, it is necessary that they should offer a considerable amount of impedance to the speaking currents, and to attain this object long-coil ringers, as Fig. 88, are used, wound to a resistance of 1000, or even up to 5000, ohms.

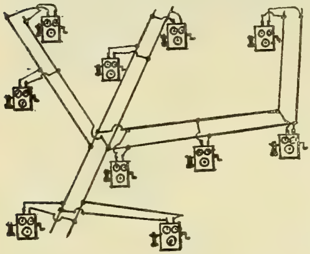


Fig. 144

The old method of joining up intermediate instruments so as to be directly in series with the line circuit has now been wholly discarded, as the impedance of the various bell and other coils which had all to be spoken through had a very detrimental effect upon the speaking currents.

Intermediate Switches.—When three stations are to be joined, and privacy is a desideratum, it is usual to employ some form of switch at the intermediate station which enables that station to speak to either one of the end stations without being overheard at the other—provision, however, being made for receiving a signal from the disengaged station at any time. If the intermediate station is the most important, and com-

munication between the end stations is not desired, an "*Intermediate Private Switch*" is used. When, on the other hand, in addition to the connections given by the last-named switch it is desired to give means of communication between the two end stations, an "*Intermediate Through Switch*" is used. The extra bell at the middle station is then connected as a shunt to the lines when connected through, so that a signal may be given when disconnection is desired.

The latter form of switch will be first described.

Ericsson's Intermediate Through Switch.—This is a form of switch which since its introduction has to a large extent

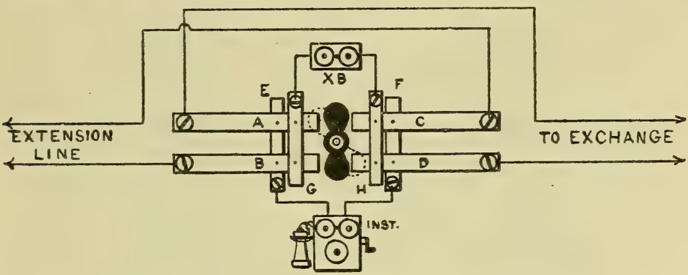


Fig. 145

superseded other forms which were in use, owing to its neatness, simplicity, and fewer working contacts. It is constructed on the principle of the old double-tapper key used in telegraphy, by means of which reversed currents can be sent to line from a single battery. For the switch, two pairs of these tapper keys are employed, as shown in Fig. 145—one pair on the right and another pair on the left, with an insulating double-ended cam pivoted between them, this cam being attached to a handle and pointer on the front of the instrument. When the handle is in the middle position, as shown, the cam does not touch any of the springs, all four of which press against the bridge contacts G and H. If the handle be moved to the left, the top end of the cam presses the top right-hand spring from its back contact to a front

contact, and at the same time the lower end of the cam presses the lower left-hand spring against its front contact. A movement of the handle to the right acts upon the opposite pair of springs in a similar manner. The connections to the instruments can be easily traced from Fig. 145.

As shown in the figure, the exchange line is through to the extension line by the springs A and B pressing against the bridge bar G, and the springs C and D against the bar H, the extra bell X B being connected as a shunt across the lines, for clearing purposes.

If the cam be moved to the position shown by dotted

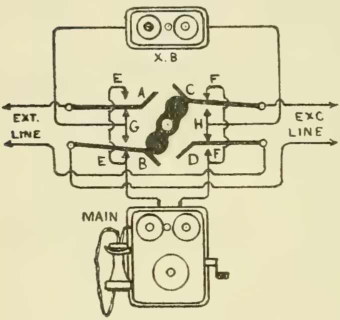


Fig. 146

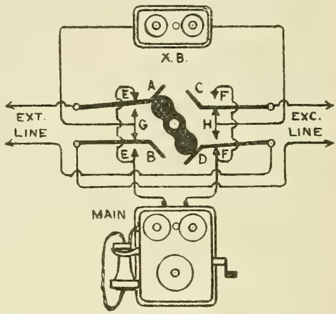


Fig. 147

lines, the springs A and D will be pressed away from bars G and H and brought into contact with bars E and F. This connects the exchange line to the station instrument, and leaves the extension line joined to the extra bell.

If the cam is turned in the opposite direction, the springs B and C are pressed on to E and F, and the extension line is joined to the "main" or station instrument, the exchange line being left connected to the extra bell.

A clearer view of the connections is given in Figs. 146 and 147, in which the different parts are lettered so as to correspond with Fig. 145. As shown in Fig. 146, the exchange line is connected to the "main" instrument, and the ex-

tension line is on to the extra bell. Fig. 147 shows the handle reversed so that the exchange is on to X B, and "main" is on to the extension line.

Fig. 148 is a view of the actual form of the instrument

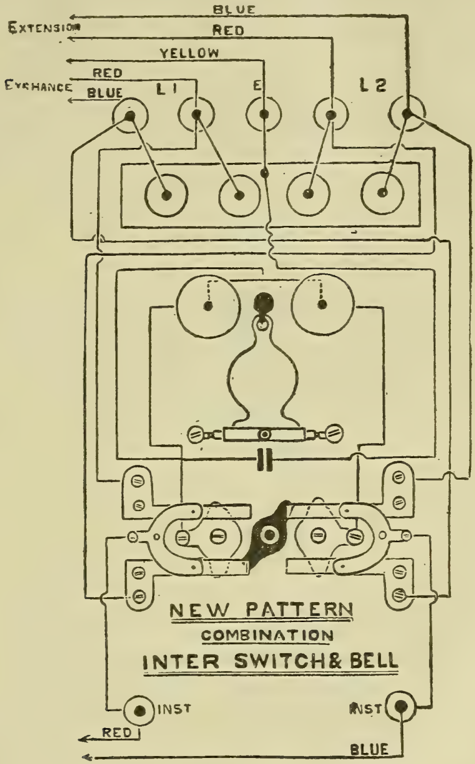


Fig. 148

combined with the extra ringer, and a drop shutter, which falls when the hammer of the ringer is vibrated. As shown, the line terminals at the top are connected to lightning arresters immediately below, similar to those shown in Fig. 102. The parts of the switch are seen as they would appear if the

front of the instrument were transparent, the horse-shoe-shaped pieces being the front contacts.

It will be seen that a connection is made to the middle point of the bell coils, which, when the shutter falls, is connected to earth through a local contact. This contact is, however, only needed for some special systems of automatic signalling.

Intermediate Private Switch.—If it is desired to prevent the two lines from being connected together, as, for example, when it is necessary to guard against a private line being connected

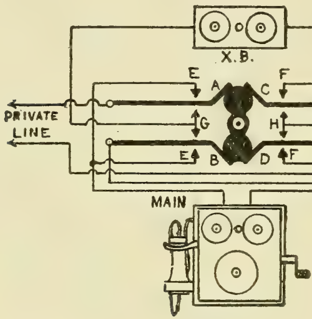


Fig. 149

through to an exchange line, a slightly modified instrument is used, so arranged that when the handle is in the centre all the line springs are disconnected. This is accomplished either by bringing the ends of the two pairs of line springs nearer together, or the working cam is made broader, as shown in Fig. 149, so as to bear on all the four line springs when in its central position. In the two side positions the connections are exactly the same as with the intermediate through form of switch, as shown in Figs. 146 and 147.

Different toned bells and gongs should be provided in connection with these intermediate switches, so that there may be no difficulty in deciding which of the two bells, the

instrument or the extension, has rung at any time, otherwise much trouble may be occasioned.

Drop Indicators.—It frequently happens that subscribers leave the office in which their telephone is fixed, and when they return wish to know if the bell or bells have been rung in their absence. In such cases an indicating disc may be attached to the bell, in such a manner that the bell hammer in moving shall release a catch, and allow the disc to fall into view. Such arrangements are, however, liable to produce faults, and it is a better plan to have recourse to *drop indicators* connected up in place of the bell coils. A trembler bell and battery may be connected up with these, so that, as long as the shutter of the indicator is down, the bell will continue to ring, but a *two-way switch* should be provided in the circuit of the bell in order to prevent it ringing at night, or when not desirable.

Common Battery Extension Instruments.—As common battery sub-station instruments do not include any source of current, either battery or magneto-generator, it becomes necessary to make special arrangements for the working of an extension instrument, so that the latter may be enabled to signal the "main" (the station nearest the exchange on an exchange line), and *vice versa.*

When intercommunication is required between the "extension" and the "main" stations, it is now the practice to provide a special battery in the circuit between the two stations for speaking purposes. An arrangement may be made for the supply of current from the central battery through retardation coils for this purpose, but this is more expensive.

Single Extension with Intercommunication.—Fig. 150 gives the arrangements adopted by the National Telephone Co. for the joining up of a single-extension instrument, giving intercommunication between all points, and so arranged that when the "main" is speaking to the "extension," conversation cannot be overheard at the central office. To accomplish this a triple form of intermediate switch is used, the

principle of which will be readily understood from the diagram. The insulating plunger is so pivoted that it may be pressed between any one of the three pairs of switch-springs—1, 2 and 3. This causes the springs to be lifted from the inner to the outer spring contacts.

Normal; Exchange to "Main" and "Extension."—In the normal position, as shown in the figure, the extension and main instruments are connected in bridge to the exchange line, so that the exchange is signalled whenever either of the receivers is lifted from its support, the other station not being disturbed.

No. 1 "Main" to Exchange.—When the plunger is pressed

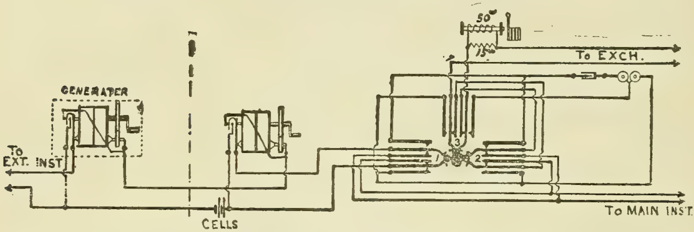


Fig. 150.—Connections for Single Extension with Intercommunication-Magneto Calling

in No. 1 switch the extension line is cut off the exchange and joined to the extra bell through the condenser, while the "main" remains connected to the exchange line without the possibility of being overheard by the extension, as would be the case in the normal position.

"No. 2" "Main" to "Extension."—When No. 2 switch is used the main instrument is connected to the extension line, and the exchange line is joined to the condenser and extra bell. Signalling between the two stations is done by the special magneto-generators. These generators are fitted with an extra "cut-out" contact, so that when the handle is turned the curved spring leaves the outer contact and makes on the inner one. Two dry cells are inserted, as shown, so

that the speaking may be independent of the exchange current supply.

"*No.* 3" *Extension to Main. Exchange Held.*—The No. 3 switch is provided for a special purpose. Suppose that the "extension" instrument has by the use of No. 1 switch been through to some outside subscriber on the exchange, and that the subscriber asks a question such that, in order to obtain an answer, it is necessary for the "extension" to consult "main." Main is called up by the use of the special generator, and is told to turn his switch to No. 3 position. Conversation can then go on privately on the extension line, while at the same time the exchange line is kept engaged

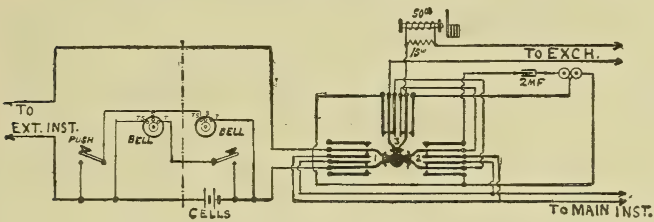


Fig. 150*a*.—Single Extension Instrument with Intercommunication Battery Calling

by the loop being completed through one coil of the extra bell. When the particulars have been obtained, the switch is again put in the No. 1 position, and the conversation with the outside subscriber continued. Such an arrangement proves very useful in practice.

Fig. 150 shows a similar arrangement in which, however, the signalling between main and extension is done by means of the extra cells inserted in the extension line, ordinary electric bell push buttons and trembler bells being used in place of the magneto generators and bells.

Extension without Secrecy.—Fig. 151 shows the connections of the National Telephone Co.'s arrangement for working an exchange instrument or "main" with one or two extension instruments on the same line. There is no switch provided.

The exchange always calls the "main" by ordinary ringer, but if one of the extension instruments is required, "main" calls it by pressing one or the other of the two push buttons

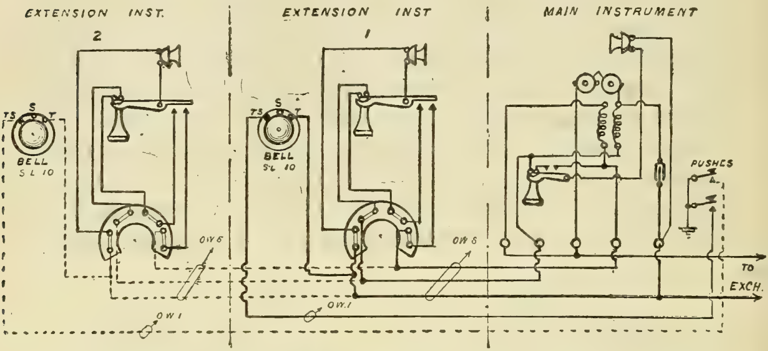


Fig. 151.—Connections for Exchange Line with 2 Extension Lines—Non Secrecy

provided, which, by means of current derived from the exchange current supply, rings the ordinary trembler electric

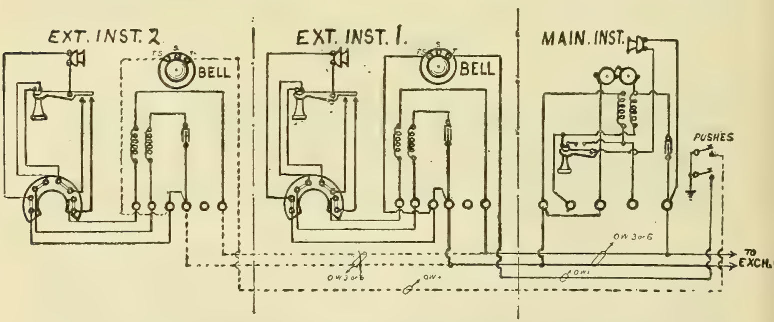


Fig. 151*a*.—Three Extension Instruments without Intercommunication

bell fitted in connection with the extension instrument. For these bells an extra line is needed between the main and each of the extension instruments. These bells are wound to 100 ohms resistance.

Any one of the stations may call the exchange by merely raising the receiver so as to close the loop circuit, but the speaking may be overheard by any one of the stations.

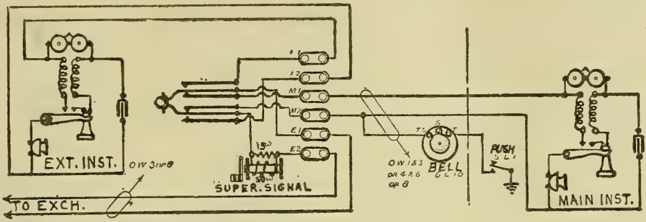


Fig. 152.—Connections for Exchange and Extension Instrument—with Secrecy

It will be noticed that only one condenser and one induction coil is used for the three instruments.

Fig. 151*a* gives the connections of an arrangement for the same purpose in which each instrument is provided with its

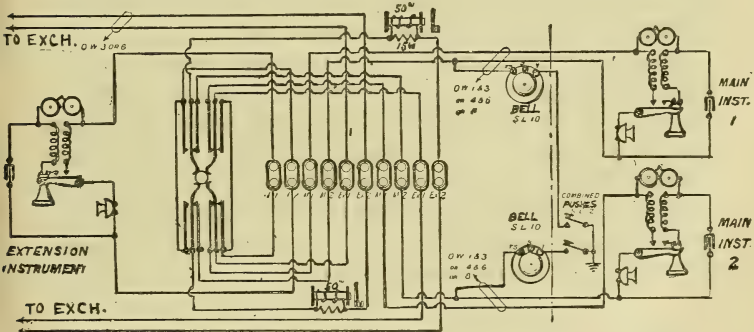


Fig. 152*a*.—Single Extension with 2 Exchange Lines—with Secrecy

own induction coil and condenser, this being preferable in certain cases.

Secrecy Arrangement.—If secrecy is desired, the arrangement shown in Fig. 152 is adopted when the extension and "main" instruments are in the same building.

A push button is used to actuate the bell and so call the

extension. On the latter operating the switch the main is entirely cut off from the exchange line. The supervisory signal is always in circuit and is operated whenever the exchange line is used.

Two separate exchange lines and "main" instruments

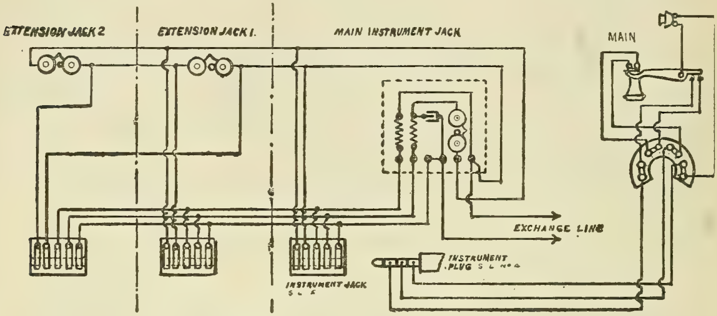


Fig. 152*b*.—C.B. Pedestal Instrument with 3 Instrument Jacks

may be connected as shown in Fig. 152*a* so that the extension instrument may be connected to either line.

Speaking between main and extension cannot be done with this arrangement, and no overhearing need be feared.

Private House Arrangement.—Fig. 152*b* shows the connections of an arrangement by means of which a single pedestal instrument may be connected in different rooms of a private house. A special plug is fitted to the instrument and this plug fits into special jacks fitted in the several rooms. The "main" bell is always in circuit with the line.

CHAPTER IX

INTERCOMMUNICATION TELEPHONES

When it is required to join together a number of offices or rooms in the same or adjoining buildings, a very convenient class of instrument to use is that which is known as the *inter-communication* or *factory* instrument. It enables any one station to instantly call up any other, without the assistance of a special switch-board and operator. A large number of different forms of such instruments are in use, but they are nearly all based on the same general principle. This consists in providing an ordinary telephone set (usually a battery set) at each station, and also a special wire for each station, this wire being run to every other station. These lines are connected to some form of switch (handle, switch-jack, or contact socket), by means of which any station set can be connected to any line belonging to another station.

Non-Secrecy System.—Fig. 153 shows the arrangement of three instruments to an 8-station system. Eight wires are made into a cable, and run to every station, where all but the line wire of the station concerned are connected to the contact studs of some form of 10-way switch or connector. Three different types of switches are shown: a circular switch at the left-hand station No. 3, a sliding switch at No. 4 station, and a cord, plug, and sockets at No. 5, the right-hand station. The 10-line wires are shown at the top, connected by branch connections, or *tee'd* to the proper contacts on each of the switches. It will be seen that, at No. 3 instrument, the No. 3 line is connected to the line terminal of the telephone set instead of to the switch, on which the "home" number is missing, and similarly at the other

stations. The second line or earth terminal of each instrument is connected to a special return wire, which, together with another special wire, is run round with the others to a central ringing battery. Local batteries are provided for the transmitters, as shown.

If No. 3 wants No. 5, the caller connects on to No. 5 of his switch, and presses his ringing button. This causes the bell to ring at No. 5 station, and when the caller and the attendant at the latter station take off their receivers, they will be in communication with each other.

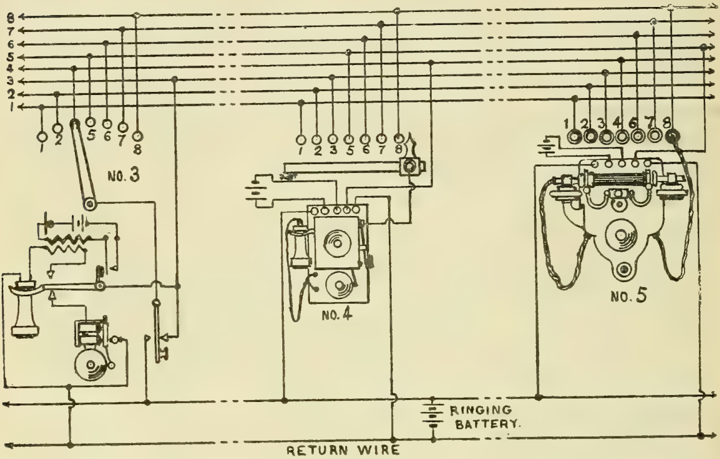


Fig. 153

It is evident that more than one pair of wires may be in use at the same time, and also that a number of, or all, the stations may be connected together at once.

Secrecy Systems.—A great drawback with these instruments is that conversations can be easily overheard, it being only necessary to connect the switch at any station on to the line of any engaged number to enable one to overhear all that is said. Many ingenious arrangements have been devised to obviate

this defect, and so produce a "secrecy" system. One of the most promising of these was known as "Sloper's" in which, by the use of a special switch, the ordinary connection to the return wires of two engaged stations were cut off by mutual arrangement, and the two ordinary lines of the two stations used to form a metallic circuit line when secrecy was required. Even this, however, was not perfectly successful, as the statical capacity of the lines not being perfectly balanced,

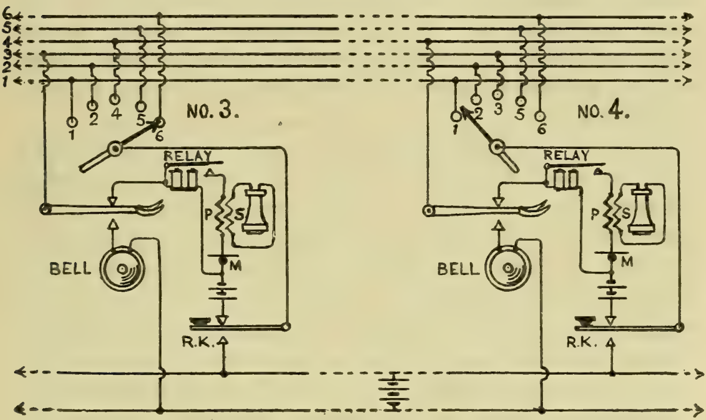


Fig. 154

and as the lines were not twisted in proper pairs, it was still possible to faintly overhear the conversation.

Sloper & Parson's System.—This is an improvement on the last-mentioned, which appears to fulfil the secrecy requirements with great success. Fig. 154 gives the connections of two instruments on a 6-line system. It will be seen that the home line is connected to the receiver hook, and the switch handle to the ringing button. A relay is connected as a shunt to the microphone and primary of an induction coil, the secondary and receiver forming an independent circuit. The microphone circuit is disconnected at the relay contact until the circuit of the speaking battery is complete through the

relay, and this circuit is only completed when some other station connects on to the home line.

To call, the switch is moved to the number of the station wanted, and the ringing key or button pressed. This rings the bell by means of current from the special common battery. The caller takes off his receiver, and listens, and the called member takes off the receiver, and moves round the switch until he obtains a click in his receiver. The two speaking batteries will now be assisting in the same circuit, the two relays operated, and the two microphones included in the speaking circuit. Overhearing cannot occur, as, until someone has connected to the listener's home line, his receiver is perfectly silent.

Another secrecy intercommunication arrangement which has been adopted is to run a separate twisted metallic circuit between every one station and every other one. Thus if there were six stations, say A, B, C, D, E, and F, there would be a line run from A to B, another from A to C, another from A to D, another from A to E, and another from A to F; also separate lines from B to C, D, E, and F; from station C, separate lines to D, E, and F; others from D to E and F, and another from E to F—making altogether 15 separate lines. For a system of 10 stations as many as 45 separate lines would be required, and for 15 stations 105 lines. It will, therefore, be seen that, although such an arrangement insures absolute secrecy, the number of lines required for any but a small number of stations becomes very formidable, and, indeed, prohibitive. The instruments required at the stations are similar to small ordinary switch-boards (for description of which see the next two chapters), being provided with calling indicators, connecting jacks, and a cord and plug, only one cord and plug being required, as no through connection is required to be made. Calls are made by pressing a battery key and causing a drop to fall on the switch-board.

CHAPTER X

SWITCH-BOARD APPARATUS

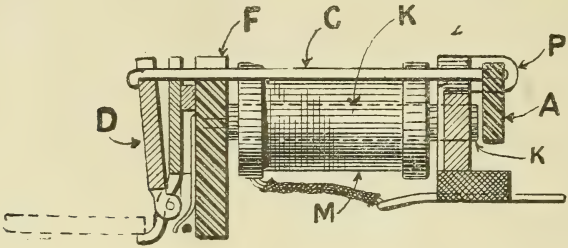
Switch-Boards.—When more than two lines have to be served by one telephone instrument it is usual to employ what is called a *switch-board* in place of a handle-switch and bells, each line being connected to a *drop indicator*, provided on the board, and special arrangements made for connecting any pair of lines together. The construction of a handle-switch for, say, four lines, although possible, would be difficult, owing to the large number of connections required to provide for the different combinations.

Switch-boards are made up of different combinations of (1) *indicators* or *annunciators*, for calling the attention of an operator when a connection is desired or conversation completed; (2) *connecting appliances*, consisting of *spring-jacks* and plugs, and usually a flexible *conducting cord* for use with the plugs; and (3) for the larger boards *supervisory arrangements*, to enable the operator to observe if the connections are properly made, etc. A telephone instrument for the operator is, of course, also necessary.

Before describing the switch-boards themselves it will be desirable to describe these different parts.

Annunciators.—For the smaller class of switch-boards these usually consist of an electro-magnet, with an armature so arranged that when it is attracted, a shutter, which was held in position by the armature, or an attachment to it, is allowed to fall, and expose a number or a coloured surface, which will attract attention. Since magnetic attraction diminishes very rapidly as the distance of the armature increases (actually as the square of the distance), the best effect

will be produced when the attraction is exerted near the pivot of the armature, and the necessary movement of the releasing catch obtained by using a long, light lever. The armature

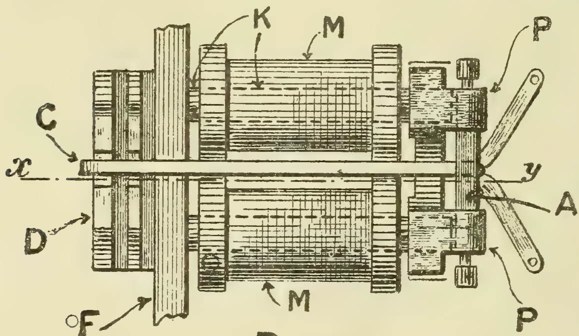


SECTIONAL ELEVATION AT $x.y.$

Fig. 155.—Full size

can then be adjusted comparatively close to the cores, but must be prevented by non-magnetic core-pins from actually touching when attracted.

The Western Electric Co.'s two-coil drop is constructed



PLAN.

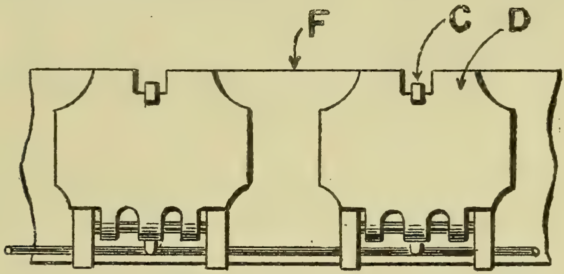
Fig. 156

on this principle, and has been very extensively used. Fig. 155 is a sectional side view, showing only one coil of the horseshoe electro-magnet; Fig. 156 is a plan; and Fig. 157

a front elevation of two shutters. D is the drop shutter pivoted at the bottom; C a lever attached at right angles to the armature, very near to the cores K of the magnet M. These cores at the other end are attached by iron screws to the strip of iron F (shown in section), which forms the yoke and support for some five or ten drops. In order to lessen friction, conical bearings are used for the armature pivots.

The ends of the magnet coils are soldered to the tabs shown at an angle on the right of Fig. 156, these forming the terminal connections.

Night-Bell Contact.—Along the bottom of the front of each strip of drops is stretched a copper wire (shown in section in



FRONT ELEVATION
Fig. 157.—Full size

Fig. 155, and in length in Fig. 157), carefully insulated from the drops. Under the frame of each shutter a thin German silver spring is clamped. When a shutter falls this spring is forced into contact with the wire by a small projection, and at night this wire and the frame of the drops form the extremities of a circuit in which is a battery and an electric bell, so that on a shutter falling the circuit is completed, and the bell rings. A 2-way switch is usually included in the circuit, so that the circuit may be broken in the day-time. The 2-coil drops just described have usually a resistance of 100 ohms.

"*Tubular*" *or* "*Ironclad*" *Drops.*—Fig. 158 shows a

form of drop extensively used and designed specially for *ring-off* or *clearing* drops. It is usually wound to 1000 ohms resistance, and it differs from the drop just described in having but one long coil, M, which is enclosed in a soft-iron case or tube, F, made out of the solid metal, the core being screwed into this. The armature A is a round disc which, as it were, forms the lid of the case; the shutter and releasing

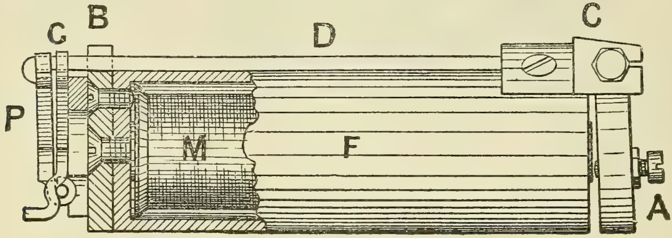


Fig. 158.—**Full size**

lever are similar to those of the 2-coil drop, so that Fig. 157 serves as elevation of both kinds. As the magnetic circuit is of very small reluctance the drop is very sensitive, and has great impedance, for which reason it must always be inserted as a shunt to a speaking circuit, and never directly in the circuit. This indicator offers great impedance to the rapidly alternating speaking currents, but only its normal ohmic resistance to the comparatively slowly alternating ringing

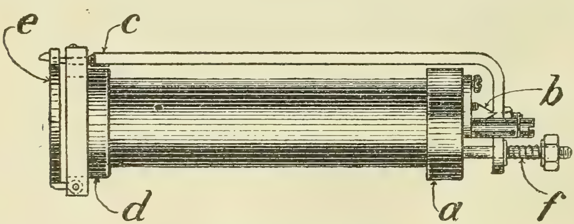


Fig. 159.—Scale $\frac{3}{4}$

currents. Another purpose which the iron jacket serves is to confine the magnetic lines of force to the inside of the coil,

and so prevent inductive effects on adjacent coils. The coil connections are brought to the outside by straight, stiff wires, which pass clearly through larger holes in the armature.

Ericsson Drop.—Figs. 159 and 160. This is a single-coil drop, which differs somewhat in principle from those described. It is one of the many forms of indicator and relay worked on the "knife-edge" principle which have lately come into use. One end of the core is made into a wedge or knife-edge form, *b*, on which is pivoted the armature. The armature passes right to the other end of the coil, and when a current passes the end *c* is attracted to the soft-iron pole-piece *d*, and the shutter *e* is released by the catch moving downward. In this manner the air space at one end is dispensed with, and the magnetic reluctance is lessened. A screw and spiral spring are used to adjust.

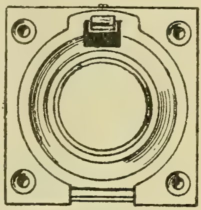


Fig. 160.—Full size

Self-Restoring Indicators.—All the drops so far described require their shutters to be restored by hand. Figs. 161

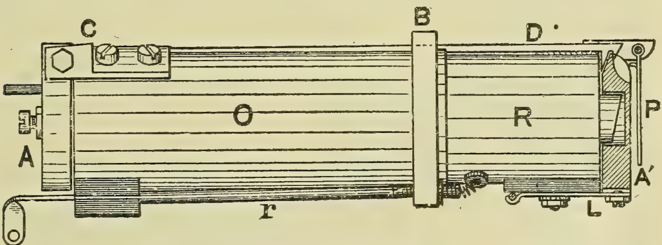


Fig. 161.—Full size

and 162 show a form in which the restoring is done automatically by means of a local battery current.

The indicator is a kind of double drop, being similar to a tubular drop, O, with another shorter ironclad coil, R, attached to one end of it, the latter being fitted with a heavy armature, A′, pivoted at the bottom, and a very light aluminium shutter, P, pivoted at the top. The core of R is prolonged, and its end

projects into a recess in A′. The coil, O, of this combination occupies the place of the drop in an ordinary system. Its armature, A, is furnished with a long lever, D, on the end of which is a detent which retains A′ in its place. On A being attracted, D is raised. A′ is released, and, falling forward against P, has sufficient weight to lift up the latter, and so

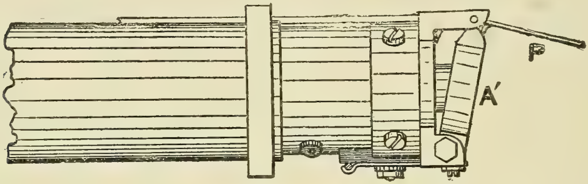
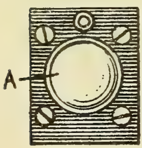


Fig. 162.—Full size

disclose the number painted on A′. Fig. 162 shows the drop in this position.

The shutter is restored by the passage of a current of sufficient strength through the coil R. This causes the attraction of A′, allowing P to fall into the vertical position. A′ cannot again fall forward as long as the current is kept on, even if D is raised.

Bull's Eye or Eyeball Indicator.—Figs. 163 and 164 show another form of self-restoring annunciator used as a clearing indicator in some of the smaller forms of common battery



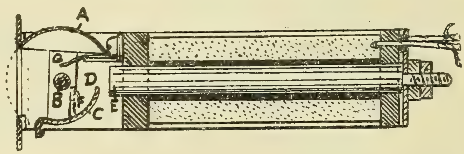


Fig. 163 Scale ½ Fig. 164

switch-boards. The indicating part is a kind of white button or portion of a hollow sphere, A, attached to a pivot, B, and counterbalanced by the curved soft-iron armature C, which gradually widens from the point D. When the core E is energised, C is attracted, moves round, and carries round A

until it occupies the position shown by the dotted line in Fig. 164, and in the front view, Fig. 163. When the current ceases A falls back out of sight. Local contacts are furnished by the springs F and G.

The Grid Indicator.—Figs. 165 and 166. This is another form of self-restoring indicator. It is made somewhat on the lines of the Ericsson drop, the armature A on the top being pressed upward normally by a thin spring, S, one end of which is clamped to a pole-piece, P, at the back, whilst the other end,

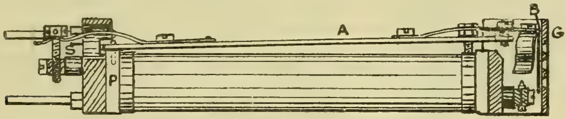


Fig. 165.—Scale $\frac{2}{3}$

or an attachment to it, B, is bent at right angles just behind a fixed front plate, G, in which are a series of openings forming a "grid." As shown in Fig. 166, a number of alternate white and black strips are painted on the armature spring B, and so arranged that in the normal position the black strips only are seen through the grid openings, but when the armature is attracted the white strips show, and thus serve to attract attention, as at C. These grid indicators were at one time much used for automatic junction-line working, but, being somewhat unreliable, have now been almost wholly displaced by relay and electric-lamp working, which has also displaced the other forms of self-restoring drops. These lamps will be described in Chapter XI.

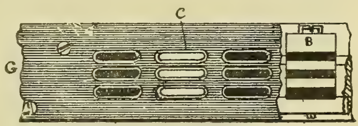


Fig. 166

Horizontal Visual Signal.—This is a neat form of self-restoring annunciator which is used in small common battery sub-exchanges in place of electric lamps. It is fixed in a horizontal position, and used as a supervisory signal. As

shown in Fig. 166, the magnet is fixed in a vertical position, with the armature A pivoted at P at the bottom. A long lever attachment, L L, is fixed to A, and bent at the top. When A is attracted, the end of L presses on a bent lug attached to a round aluminium disc, D, pivoted at C, and raises the latter to the window W in the cord shelf. When the current ceases, D falls back from W. This instrument is known as the "6-A visual signal," but is sometimes called the "sixpenny" signal from the appearance of the aluminium disc.

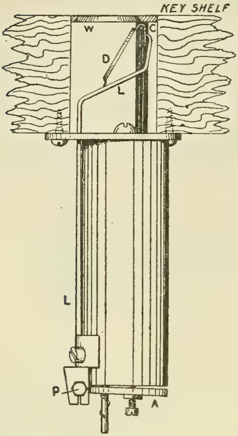


Fig. 166*a*.—Scale $\frac{2}{3}$

Mechanically-Restored Drops.—So far, the so-called "self-restoring" indicators described have been restored by the aid of electricity, but there is another similar class of drop in which the restoring is done by mechanical means. In this class the indicator and connecting spring-jack (see subsequent description) are usually combined as one piece of apparatus, the jack being below, and it is so arranged that the act of plugging into the jack, consequent upon a fallen drop, causes

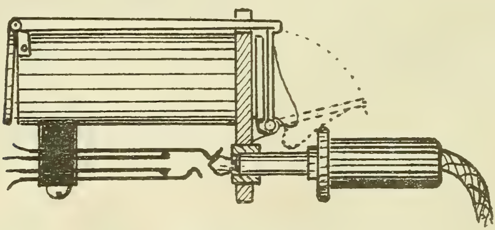


Fig. 167.—Scale $\frac{2}{3}$

the lifting of the drop shutter into its normal position. There are a large number of varieties of these instruments, the

simplest being those having a kind of cam projection on the front of the drop shutter, which, when the plug is inserted in answer to a call, is lifted upward by an enlarged collar on the plug, so as to carry the shutter to its normal position, as shown in Fig. 167.

Another form of this kind of apparatus is shown in Fig. 168, in which the bottom long-line spring of the spring-jack A has a kind of stirrup loop formed on its end. This is bent upward so as to intervene between the end of the ironclad magnet and the drop shutter D. The shutter has attached a projecting-piece, which passes to the back through a hole in the frame-piece F, so that when the shutter falls the projecting

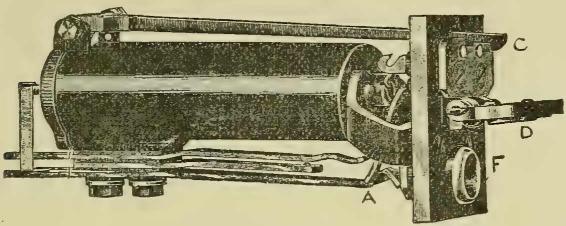


Fig. 168

piece passes inside the top of the stirrup loop. When the answering plug is pressed into the jack, the sleeve of the plug forces down the spring A, and the stirrup loop moving down with it, bears on the shutter projection, and raises the shutter until it is held by the armature-lever catch C. These instruments are made by the American Electric Telephone Co.

In another form the end of the plug on entering the jack carries or presses back a lever or rod, having a projection at the front of the shutter which lifts the latter into position.

These combined jacks and plugs are very convenient arrangements; as, from the fact that the answering jack is directly beneath the drop, the operator is immediately guided to the right jack without any mental effort, so that time is saved and there is no risk of mistake.

Spring-Jacks.—These are now very important adjuncts to

the telephone, being used on nearly all kinds of switch-boards. They are very varied in form and construction, and are usually designated as 2-point, 3-point, 4-point jacks, etc., according to the number of springs and connections with which they are provided. They are generally arranged in rows of five, ten or twenty, fitted on to an ebonite strip or to a skeleton metal frame, ebonite being in the latter form only used for insulating purposes.

The name is generally shortened to the term "jack."

Break and Branch Jacks.—Jacks are also divided into two classes, *break* and *branching* jacks, according to whether the connecting plugs, when inserted, cause the springs to break away from contacts in the jack, or whether the springs are normally free from contact, and only make contact with the various parts of the plug when it is inserted.

Break-jacks were almost exclusively used at one time, but they are now rapidly giving way to branching-jacks. They are mostly used in small switch-boards, while in large switch-boards branching-jacks are now almost exclusively employed.

Fig. 169 gives a view of two 5-point break-jacks forming part of a strip of twenty jacks. The springs are laid edgewise in slots sawn in a strip of ebonite, and are kept in position by thin strips of ebonite, which are fitted in recesses cut in the sides of the springs, and screwed down to the block, as shown. The fifth spring of each jack is connected to a brass socket, shown by dotted lines, fitted into another strip of ebonite ($11\frac{1}{2}$ inches long), which forms the front of the jack, and on which the numbers of the jacks are engraved. The sockets are usually bored out to 252 mils diameter, to accommodate the plugs of $\frac{1}{4}$-inch or 250 mils diameter.

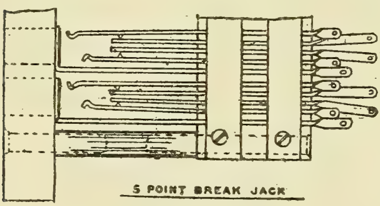


Fig. 169.—Scale $\frac{1}{2}$

When a plug is inserted in a jack the two outer springs are pressed away from the two shorter inner springs, and thus *break* contact.

Fig. 170 gives a view of a strip of ten 4-point jacks con-

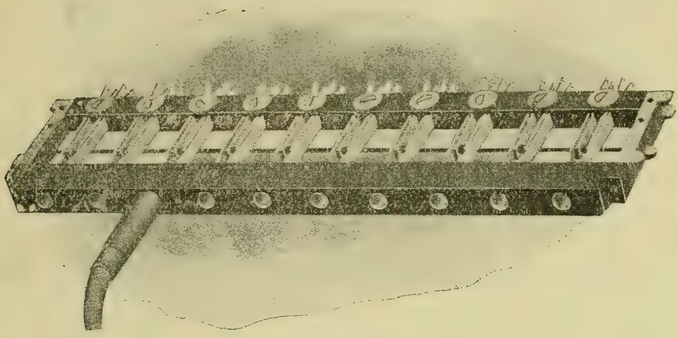
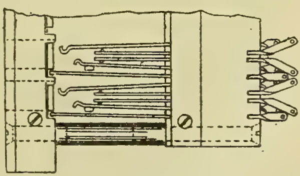


Fig. 170

structed in a somewhat similar manner to those shown in Fig. 169.

Fig. 171 shows part of a strip of 7-point jacks. These are similar to the 5-point jacks, but the spring connection to the sockets is not permanently connected, being pressed away from contact (when a plug is inserted) by an insulating stud attached to the shorter of the two outer springs.



7-POINT BREAK JACK
Fig. 171.—Scale ½

The 5-point and 7-point break-jacks are those mostly used on small switch-boards.

Branching-Jacks are constructed in a similar manner to break-jacks, but are usually less complicated.

The 3-point jack is the one most extensively used, and one form is similar to the 5-point break-jack, except that it lacks the two short inner contact springs.

Fig. 172 shows in section and plan a form of 2-way branch-

ing-jack made by the Kellogg Co. of America. This has only one contact spring.

Fig. 173 shows a form of 3-point branching-jack made by the Western Electric Co., and used in their common battery

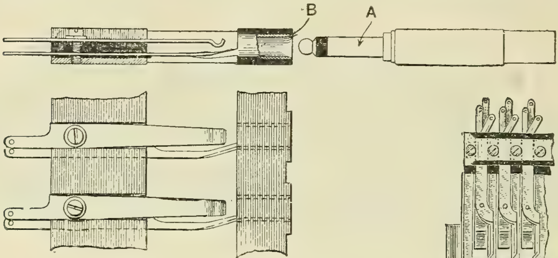


Fig. 172.—Scale $\frac{1}{2}$

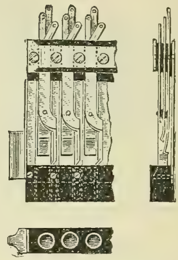


Fig. 173.—Scale $\frac{1}{3}$

switch-boards. This jack differs in construction from the forms described, the springs all being made to bear on one side of the plug. The bush connection spring is used to serve as a stop. The advantages of this mode of construction are that the plug is pressed heavily against the socket, a good contact being thus ensured, and the ends of the springs made more readily accessible for cleaning purposes.

A half-sized view of a full strip of 20 of these jacks is shown in Fig. 174, which also shows the method of numbering adopted by the National Telephone Co. All such strips are

Fig. 174.—Scale $\frac{1}{2}$

numbered alike, and it will be seen that the Nos. 0, 5, 10, and 15 of the strip are rendered prominent by large dots, as a guide to the operators. The numbers are really white on a black ground. The strips measure $7\frac{5}{8}$ inches by $\frac{3}{8}$ inch, and the jacks are set $\frac{3}{8}$ inch apart.

Plugs.—These are made either 2-way or 3-way. Fig.

175 shows a sectional view of a 2-way, and Fig. 176 of a 3-way, plug. In the former the brass tip of the plug is carefully insulated from the sleeve, and is connected by means of

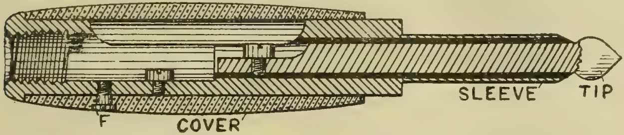


Fig. 175.—Full size

an interior rod to a terminal in the body of the plug, and another terminal connects to the main body and sleeve. The terminals are often in the form of soldering tabs, and great care is then necessary to prevent short-circuiting of the plugs by solder.

The 3-point plug is, in addition, provided with a small brass collar or ring, R, which is connected by means of an

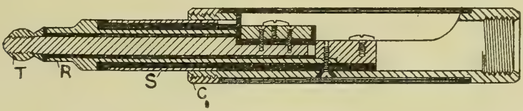


Fig. 176.—Full size

insulated sleeve to a third soldering tab or terminal in the body of the plug. Being more complicated, much more care is needed to prevent short-circuiting and other faults, as the space is so limited.

Ebonite or fibre covers are fitted over the bodies of the plugs, being fixed in position by a screwed metal collar, as shown at C in Fig. 176, or by a small set screw, as shown at F in Fig. 175. An improvement adopted recently is to put the set screw through from the inside of the body, riveting the end a little to prevent it passing back, then slotting the end for the screw-driver, so that it may be screwed down below the surface of the body, and so release the cover. This prevents the screw coming out and getting lost.

The connecting cord is thickened at the end, and is screwed into a tapped hole in the base of the plug. By this means the cord is firmly held, and all strain is taken off the connections.

Common Battery Plug.—Fig. 177 shows a special form of plug used by the Western Electric Co. for their common battery switch-boards. It is provided with an insulated thick metal ring or collar, A, in addition to the ordinary ring

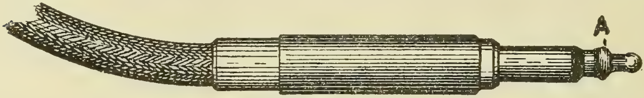


Fig. 177.—Full size

of the 3-point plug. This ring is provided to prevent the possibility of the tip and ordinary ring being short-circuited when the plug is passing through the socket of the jack. Fig. 178 is a section of this plug, and it shows how the conductors T, R, and S of the 3-way cord are connected to the plug.

Connecting Cords.—The flexible connections required for the connecting plugs have always been a great source of trouble owing to the conductors, of thin stranded copper wires, copper or brass tinsel, sooner or later being wholly or partially fractured, or filaments pierce the silk or cotton

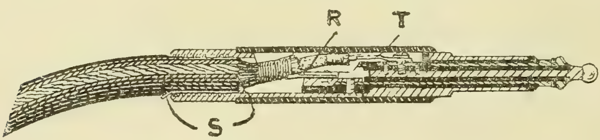


Fig. 178.—Full size

braided coverings, and so cause short circuits. The point of greatest trouble in this respect is near the base of the plug, where the bending is sharpest and most frequent, and the liability to such faults is greatly augmented by the action of the operators pressing on the cord with the hand when inserting a plug in a jack. This habit plays havoc with the cords, and is very difficult to eradicate.

Since the advent of common battery working it has become important that not only shall the conductors furnish a path for the weak speaking and ringing currents which were formerly employed, but, in order to avoid risk from undue heating, they must be of sufficient carrying capacity for the comparatively strong normal ringing and speaking currents, and also for the strong currents which may result from the accidental short-circuiting of resistances in the circuits.

Another trouble with common battery working is caused by variations in the resistance of the cords (owing to the intermittent contacts of severed strands of a conductor) giving rise to annoying noises on the line—these noises being due to the microphonic effect of the permanent current.

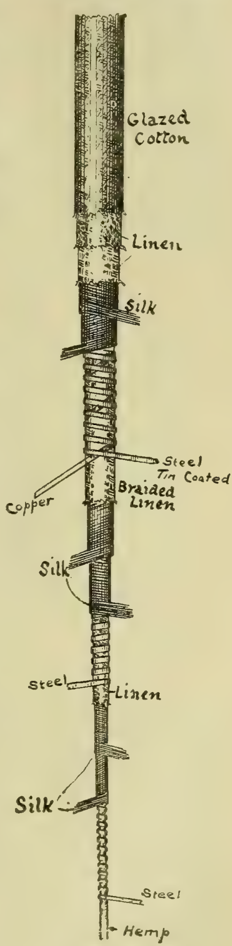


Fig. 179—Full size

Steel-Conductor Cords.—To overcome the difficulties mentioned above, a cord, made up as shown in the detailed sketch, Fig. 179, has been introduced by the Western Electric Co. It is a 3-way cord, the conductors of which are spirals of flat steel wire about 8 mils thick and 25 mils wide, the conductivity of the outer spiral being increased by an extra spiral of copper strip wound in the opposite direction, this conductor being used for the strongest current. The core of the cord is of hemp twine, which takes up any tensional strain, such as is met with when the plugs are pulled out of the jacks by the cord. Owing to its stiffness, this cord will only bend slightly, so

that the elasticity point of the steel is not exceeded unless excessive force is used. If a spiral should break, the two broken ends are drawn apart, and, consequently, no microphonic contacts are formed. Fig. 178 shows how the cords are connected to the plugs.

From a comparative test, it was found that, with very rough handling, the number of times the steel cords would stand bending was 10,000, as compared with 1500 times in the case of a tinsel-conductor cord. Owing to the length of the spiral, the resistance of the steel conductor is higher

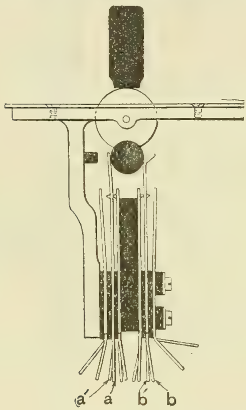


Fig. 180

Scale ½

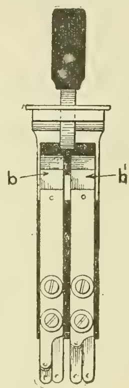


Fig. 181

than that of a tinsel conductor, the inner or "tip" conductor having a resistance of about 1·22 ohms per foot of cord, the middle or "ring" conductor about 1·45 ohms per foot, and the outer or "sleeve" conductor having about ·186 ohms per foot of cord. Tinsel cords for common battery working have a resistance of about ·086; ·079, and ·043 respectively. The "sleeve" conductor of the steel cord will safely carry a current of 5 amperes.

Supervisory Keys.—These are used on switch-boards intended for more than about twenty-five subscribers, and are for the purpose of enabling the operators to connect their telephones

or ringing current to any of their lines with the least possible trouble or delay. Separate keys were formerly used for speaking and ringing; but these are now usually joined together, and operated with one lever, this resulting in much improvement in their working.

Kellogg Combined Listening and Ringing Key.—This key, shown in Figs. 180 and 181, is very simple and effective, and occupies but little space, for which reason it is now much used. Four long springs are each fitted between two shorter springs. The long springs are moved by the ebonite cross-

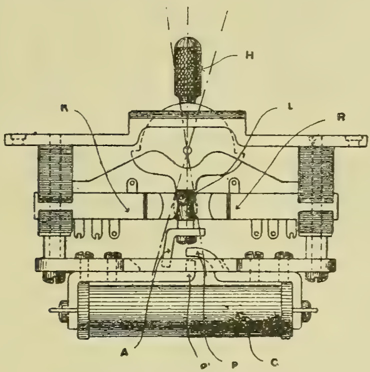


Fig. 182

Scale $\frac{1}{3}$

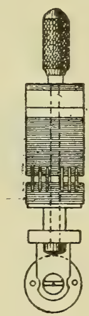


Fig. 183

piece fitted on the metal disc, to which the operating handle is screwed. The left-hand sets of springs (Fig. 180) are for ringing, and require a continuous pressure of the handle to the right, while the right-hand sets of springs are used for listening on any line to which the corresponding plug and cord has been connected. The bend at the top of the long springs of the latter sets causes the handle and disc to become fixed when moved to the left. It will be seen that this key is really a combination of four keys operated by the same lever.

A key operated in a similar manner is shown in the upper part of Figs. 182 and 183. The springs are in this case fixed horizontally instead of vertically as in the Kellogg, a view of

the twelve springs being given in Fig. 184. The round ebonite wedge L on the bottom of the pivoted disc is pressed in between the ends of the two long springs on the left for speaking, and between those on the right for ringing. The springs, it will be seen, are set in slots in four blocks of ebonite, and are clamped to the top plate by two screws, which also clamp a plate having an electro-magnet attached.

Ringing Control.—In order to economise the operator's time, it is now often the practice in busy exchanges to arrange for the ringing on junction lines to be automatically controlled after the first operation of the ringing key. Long soft-iron pole pieces, P and P′ (Fig. 182), are connected to the ends of the core of the single-coil electro-magnet C, the ends being shaped as shown, and brought near to each other. When the

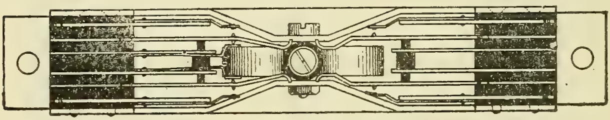


Fig. 184.—Scale $\frac{1}{3}$

key is turned into the ringing position, a soft-iron armature, A, clamped by the screw which carries the wedge L, is brought near the pole pieces of the magnet, and it is so arranged that, while the ringing current passes through the connected line, a current also passes through the magnet C, and holds the armature A, and therefore the key, in the ringing position, but directly the ringing current is stopped by the lifting of the subscriber's receiver, A is released, and the key falls back to its central position. The keys are often used without the ringing control, in which case the magnet and armature are omitted.

Many different forms of *ringing control*, or methods of "machine" ringing, as it is called, are in use, some depending upon mechanical catches released by an electro-magnet, others on the expansion of a metal by the heating effect of the current, others on the escape of a gas or liquid from a closed vessel,

on so-called *dash-pot* principles. The two latter systems enable the length of time allowed for the ring to be regulated. The method shown in Fig. 182 is the invention of Mr W. Aitken.

A type of ringing control supplied by the Western Electric Co. is shown in diagrammatic form in Figs. 256 and 259. The magnet is shown turned at right angles to its proper position so as to show the coils. The latter are four in number, all polarised in the same direction by the operating current so as to magnetise two long bar pole-pieces, by which the soft iron armatures attached to the press keys are held (after being pressed down) as long as current circulates through the coils. The one four-coil magnet is common to two or more keys.

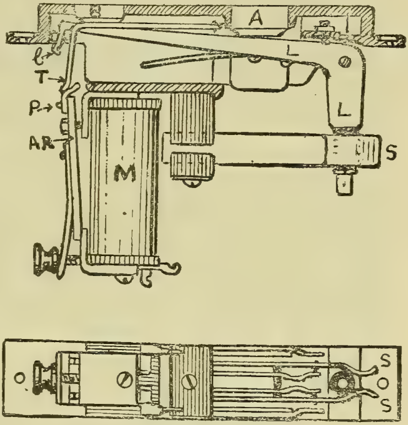


Fig. 184*a*.—Double Automatic Ringing Key

Ringing Vibrator.—This is made up of the coils, armature, and polarising magnet of a *ringer*, but in place of the hammer and gongs a grid shutter is attached to the armature. The combination is arranged behind a small grid. On the instrument being joined in the generator circuit the shutter vibrates when a ringing current is passing to line, but is inactive if there is a break in the circuit; consequently, the operator is enabled to note either circumstance.

Automatic Ringing Key.—Fig. 184*a* shows the double button key used on some C.B. switch-boards. For ringing, button A is pressed, operating the lever L so as to open the springs SS and at the same time depressing lug l so that it hooks on to projection P attached to armature AR of magnet M. When M is energised AR is attracted, l is released and L rises; or release may be effected by pressing button B which presses the end of trigger T between l and P and thus unlocks.

CHAPTER XI

RELAY AND LAMP SIGNALLING

As before mentioned, in exchanges of importance the various forms of electro-magnetic drops and annunciators have been almost completely displaced by miniature incandescent lamps, working in conjunction with relays and some permanent source of current supply. These have answered their purpose so well that it would appear that in this respect at least the telephone switch-board has reached a point of finality.

Relays.—In the working of electrical apparatus it is often necessary to operate certain instruments, such, for example, as switch-board indicators, from a distance. To send a sufficiently strong current from the distant point would entail the use of powerful batteries or other generators, a large proportion of the energy of which would be lost on the line. In such cases it is found to be much more economical and satisfactory to employ what are termed *relays*, which are simply electro-magnets wound generally with a large number of turns of wire, and fitted with light and sensitive armatures. When attracted, the armatures cause the closing of local circuits of comparatively small resistance, in which are included local batteries, which will give sufficiently powerful currents to effect the desired operation.

Many forms of relays are now used in telephony, especially in connection with the common battery system, which, in fact, is sometimes called the *relay* system.

Line Relay.—Fig. 185 shows a simple and efficient form of relay made by the Western Electric Co. much used in common battery work. A soft-iron core extension is bent under the coil, and has a notch in the opposite end, in which rests

one end of the armature, the lower end of which is bevelled to a knife edge. The armature is adjusted, and its forward motion limited, by a brass nut, *C*, on a screw let into the core. The relay contact is made by a screw, B, which is tipped with platinum. When operated, this screw presses against

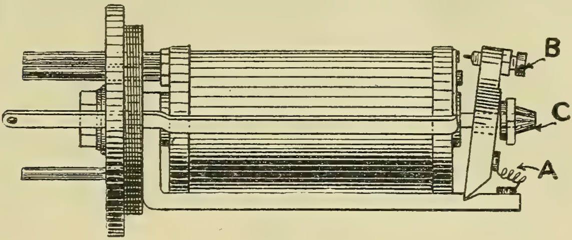
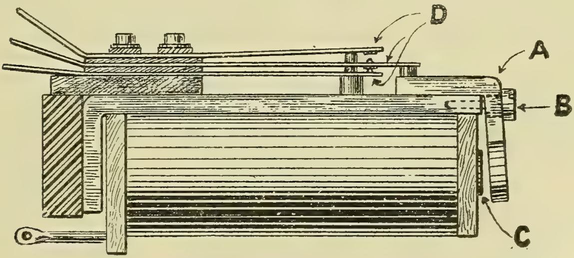


Fig. 185

another contact fixed on the fibre end of the coil, forming part of the *local circuit*. This latter contact is connected by insulated wire to a soldering tab at the opposite end, and a screw in the centre connects to the armature and other metal work, which forms the remaining part of the local circuit. The



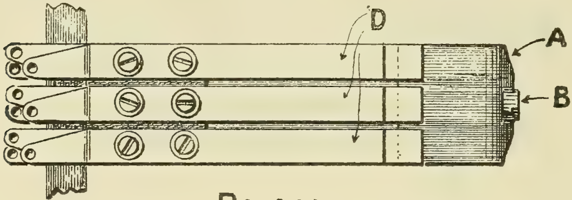
ELEVATION

Fig. 186

spiral spring A ensures a good contact with the armature. The coil-wire terminals are also brought out to insulated soldering tabs. A cylindrical metal cover, which is not shown, is passed over, and screwed on, rendering the whole dust-proof. This is called a single *make* relay, and is usually

wound with 11 mils wire to a resistance of 60 ohms. It works with a current of 20 milliamperes.

Kellogg Pattern Relay.—Figs. 186 and 187 show another sample of the knife-edge relay which is now very popular. The armature is bent nearly at right angles, and rests at A on the end of the extended pole-piece. The screw

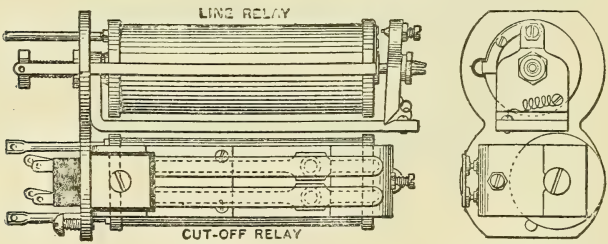


PLAN

Fig. 187

B keeps the armature in position. When attracted, the latter rocks on the knife edge, and insulated studs on the upper end raise the long centre springs at D from the lower springs into contact with the upper short springs shown.

In Fig. 187 the instrument is shown furnished with a triple set of three springs, and it is known as a *triple make and*



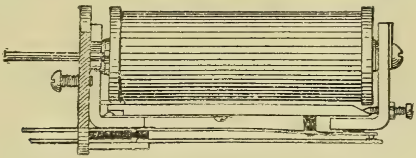
Side Elevation Front Elevation

Fig. 188

break relay. It can, of course, be arranged in a simpler form according to the number of sets of springs employed. These relays are generally wound to a resistance of 250 ohms,

and the triple form operates with a current of about 30 milliamperes.

Western Electric Co.'s Cut-Off Relay.—This is a form much used in C.B. working, and is shown in Figs. 188 and 189 in combination with a line relay. Both poles are fitted with fixed soft-iron extension-pieces, to one of which the armature is



Plan of Lower (Cut-off) Relay
Fig. 189

attached at the side by means of a spring, and normally presses inward against the pointed end of an adjusting screw, shown on the right. When operated (by a current of about 73 milliamperes) the armature moves *away* from the coil to the pole-piece and the lower springs are pressed away from contact by insulating studs which pass through holes in the upper springs. These relays are wound with wire of 12·6 mils diameter to a resistance of 30 ohms.

Retaining-Coil Relays.—Relays are sometimes arranged so that, when once they have been operated by a momentary current, the armatures will remain held until specially released.

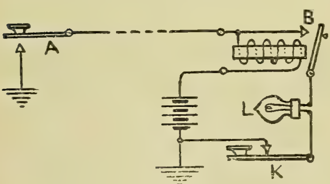


Fig. 190

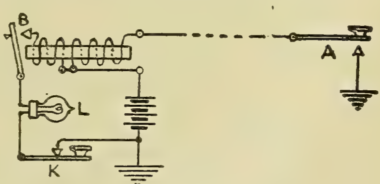


Fig. 191

This can be accomplished with only one winding on the coil, as shown in Fig. 190, where by pressing the key A for a moment the battery circuit is completed through the relay coil C,

the armature is attracted, and the contact B is closed, completing another path for the current through the lamp L and key K. The armature will remain held up until key K is pressed, and the battery circuit broken.

It is more usual, however, to have a second low resistance winding on the relay, as shown in Fig. 191, and to use this to retain the armature. The action will be readily understood from the figure.

When once an armature has been attracted, less ampere turns are required to retain it, so that the turns, or the current, or both, may be reduced.

Lamp Signals.—The advantages of lamp signals are many, such as:

(1) When glowing, they attract attention more certainly than drops.

(2) They occupy much less space than ordinary drops.

(3) They are completely "self-restoring."

(4) When damaged, they are very easily replaced.

(5) They can be fixed in any position.

They also have their disadvantages, such as:

(1) They require in conjunction with them an electro-magnetic relay, which makes the boards more costly and complicated.

(2) They are more liable to damage by excess of current.

(3) They need more current for working, and this entails more expense for current generators.

These drawbacks are, however, far from outweighing the very decided virtues of the lamps, and there can be no doubt that their adoption results in a decided advantage.

When first employed, the lamps were connected directly in the loop-line circuit, which was normally disconnected at the sub-station instrument. When the receiver was lifted up the loop circuit was completed, and the lamp lit by current from a central battery. This plan, however, although very simple, did not work well owing to the various and varying conditions of the lines in regard to resistance, leakage, etc., the

consequent changes of current strength, and the sensitiveness of the lamps to these changes. The universal practice at present is to use a relay in the line circuit, or as a shunt to that circuit, and to include the lamp and necessary source of current in the local circuit of the relay.

The relays needed for the lamps may be fixed apart from the switch-board in some position easily accessible for testing and repairs.

Lamps.—These are small carbon filaments enclosed in an exhausted sealed glass tube of about ¼-inch diameter. The ends of the filament are connected to platinum wires which pass through the sides of the glass tube, and are soldered to thin brass plates cemented to the sides of the tube, as shown in Fig. 192 at A. The resistance of the 24-volt lamps when cold is 520 ohms, and when incandescent and taking a current of 0·11 ampere, is 240 ohms, the light then given being about one-third of a candle.

Lamp-Jacks.—The lamps are held in position, and connection made to them by jacks of somewhat similar form to ordinary spring-jacks, except that springs of equal length are used, as shown at B in Fig. 192, which shows part of one form of strip. When the lamps are in position, the springs bear on the brass plates of the lamps, and the holes in the front ebonite strip through which the lamps are inserted are closed by *lamp caps*, which are small brass sockets, in the front of which opal plano-convex lenses are fitted, as D, Fig. 192. These caps protect the lamps from injury, and serve to spread the light, so that a signal can be plainly seen from any point at the front of the board. The opal caps are often marked in such a manner as to inform the operator

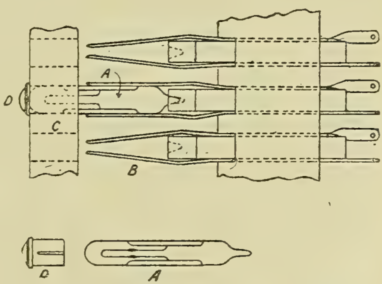


Fig. 192.—Scale ½

to what privileges the subscribers to which they belong are entitled. See Chapter XVII.

The lamp-jacks are made up in strips to correspond in size and number of jacks to the spring-jack strips, as shown in Fig. 193, which represents a strip of twenty as made by the

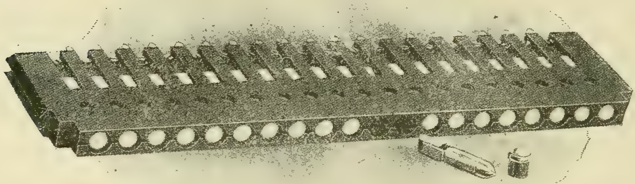


Fig. 193

Kellogg Co. The two kinds of jacks are generally used in conjunction with each other, this greatly facilitating the operation of the switch-boards by keeping the signal and the answering jack close together.

Lamp Extractor.—For the withdrawal of the lamps from the jacks the shank of a magnum bonum pen forms a good substitute for the ordinary steel-clip tool which is supplied for the purpose.

Lamp Guards.—When the lamps are fitted on the cord shelves of switch-boards, as when used for clearing signals, falling plugs are apt to fracture the opal caps. To prevent this, such lamps are specially protected by guards, consisting of a metal ring fitted with crossed wires or open cage work, which are fitted over the ordinary lamp cap, or are made as part of it, as in Fig. 194.

Fig. 194

Switch-Board Illumination.—As the signal lamps attract attention by contrast, and as they do not give a powerful light, it is important that they shall

be screened from the light of the comparatively brilliant lamps used for illuminating the switch-board, and this especially applies to the clearing lamps fitted on the cord shelves. To achieve this purpose the illuminating lamps, which are in a row at the top and front of the switch-board, are provided with long, continuous reflectors of silvered glass, so arranged that the light is thrown mostly on the upper part of the front of the switch-board, and the lamps on the cord shelf are completely screened.

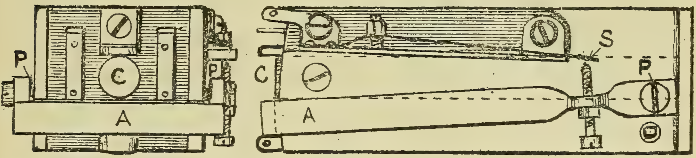


Fig. 194*a*.—Slow-Acting Relay

Slow-Acting Relay.—When a relay is required to be operated by an alternating current, as in certain cases of party-line working, trouble is experienced with ordinary relays owing to the "chattering" of their armatures. In such cases a slow-acting relay, such as shown in Fig. 194*a*, is employed. A single coil is used and the armature A is comparatively heavy and long, being more than twice the length of the coil. It is pivoted on both sides at P and rests just below the core end C when inactive. When energised the inertia of the mass of metal is so large as to prevent it moving sufficiently to break the contact at S in the time between two undulations of the current, so that the contact is steadily maintained.

CHAPTER XII

SMALL SWITCH-BOARDS

For centres where but a comparatively small number of lines are to be provided for, up to, say, about twenty-five or thirty, somewhat simple working arrangements will answer, but for more than this number it becomes necessary to provide special means for making the necessary connections as quickly as possible, and for the efficient supervision of the connections when made. The small and simpler boards will first be described. These may be divided into two classes—(1) the *Cordless*, in which the connections are made by means of plugs only; and (2) the *Plug and Cord*. The latter may also be subdivided into *Single* and *Double Cord* boards.

Cordless Boards.—This class of board has now become very popular, as it is very simple in working, and is free from the trouble and annoyance caused by defective cords. The form of board now to be described is sometimes called the *pyramid* board, owing to the peculiar arrangement of its connecting-jacks. Fig. 195 shows a 6-line board made by the Ericsson Co. Each line—it will be seen in the diagram of connections of a 3-line board, Fig. 196—is provided with two connecting-jacks and a plug, and each line is also connected to other jacks, so that by means of the plug it may be connected to any other line on the board. The board is made complete with hand-generator, hand-micro-telephone, and polarised bell. In Fig. 196 the line wires are marked at bottom 1, 2, and 3. Taking No. 1 line, it will be seen it is connected by branches from the two wires to the right-hand springs of the left-hand jacks of the two bottom rows, and to the left-hand springs of the jacks on the row above, marked 1-2 and 1-3, the right-

hand springs of these being connected to lines 2 and 3 respectively. The other lines are connected in a similar manner. The left-hand springs in the lower row of jacks are connected to the drops, and the plugs—which are 2-point—are normally left in these jacks. When a drop falls, the plug in the corresponding jack, say No. 1, is moved into the jack immediately above, which connects the line to the service instrument. Having ascertained the number required, say No. 3, No. 1 plug is inserted in No. 3 service-jack, the generator operated to ring No. 3, and when an answer is obtained the same plug is moved to the jack numbered 1-3. When conversation is completed a ring is given by sub-stations, causing the called line drop (No. 3), (which is connected as a shunt), to fall, and the operator thereupon restores the calling-line plug (No. 1) to its normal position. The drops are as shown in Fig. 159, and are wound to 1000 ohms resistance.

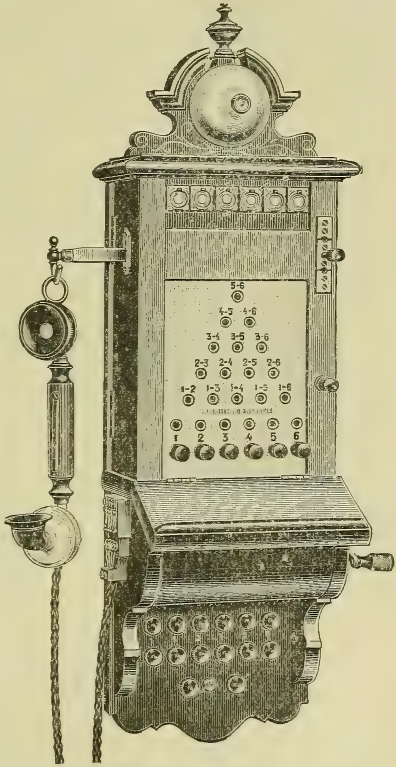


Fig. 195

Single-Cord Boards.—Figs. 197 and 198 show a 6-line switch-board of a much-used type, and Fig. 199 gives the connections. The lines are connected to soldering tabs at the back, and from these connections are made to the outer springs of 5-point break-jacks fitted below the tubular drops, which

latter are connected to the inner springs of the jacks. The short outer springs are also connected to the plug-tip strand of the connecting cord, and the long spring to the sleeve strand of the cord. Each line has thus a connecting cord and plug permanently joined, and to make a connection the plug corresponding to one number is pressed into the jack of

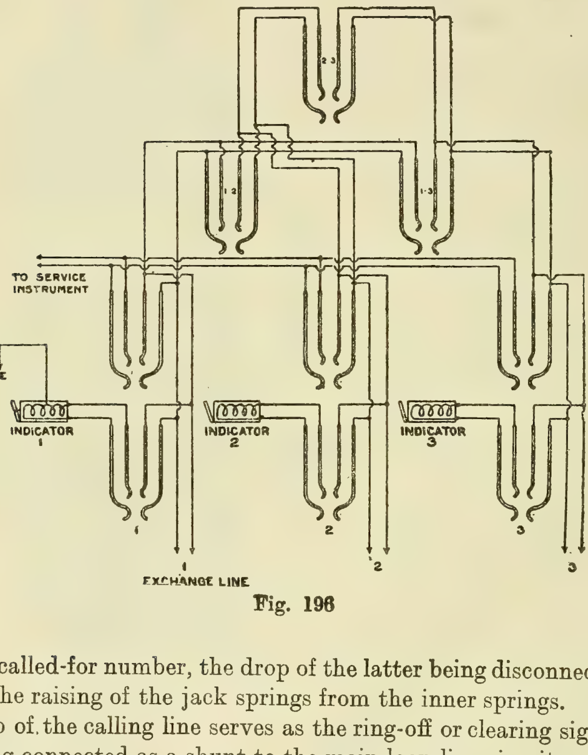
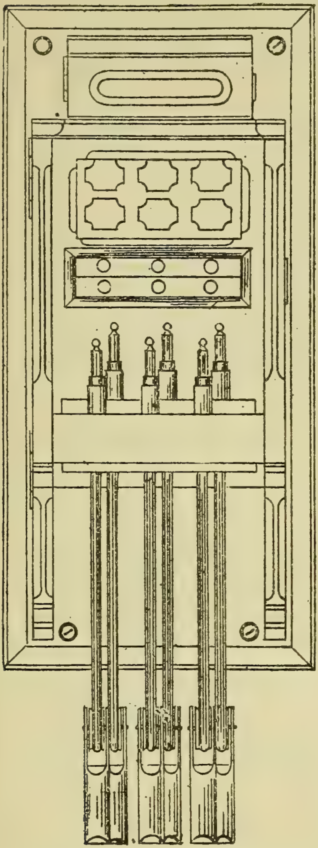


Fig. 196

the called-for number, the drop of the latter being disconnected by the raising of the jack springs from the inner springs. The drop of the calling line serves as the ring-off or clearing signal, being connected as a shunt to the main loop-line circuit. The drops are wound to 1000 ohms, and, being of high inductance, they offer great impedance to the speaking currents.

For the operator an ordinary telephone set is provided, to the line terminals of which a 2-point plug and cord are

connected. The plug is inserted into the jack of a calling



ELEVATION

Fig. 197

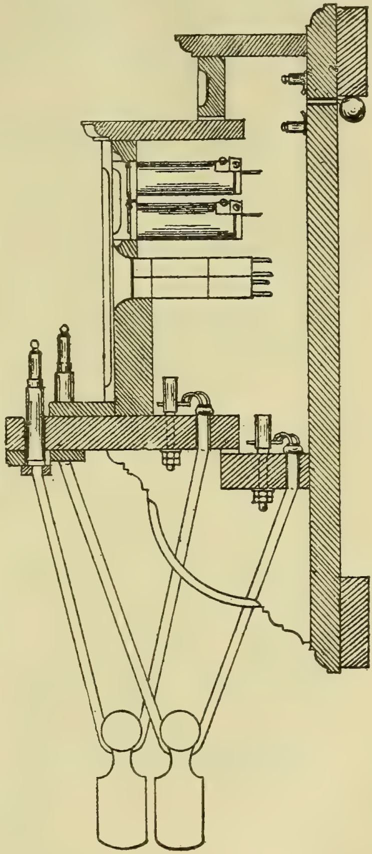


Fig. 198

line, the required number ascertained, and the plug withdrawn and plugged into the called-for line-jack. A ring is

then given, and on an answer being obtained the plug of the called line is inserted into the jack of the calling line, and the operating plug withdrawn.

Double-Cord Boards.—By disconnecting the cord connections

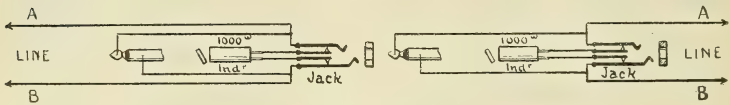


Fig. 199

from the jacks of the single-cord board, Fig. 199, it is clear that two lines could be joined by an independent connecting cord, with a 2-point plug at each end, by plugging into the two jacks, but, as both drops would then be cut out, there would be no clearing signal. The connections of the *double-cord*

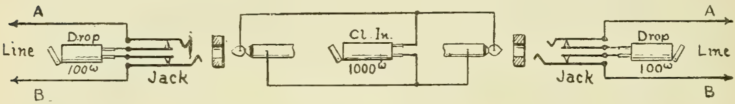


Fig. 200

switch-board are of this nature, as shown in Fig. 200, and to provide for clearing signal a tubular drop (1000 ohms) is connected permanently as a shunt across the two strands of the cords. As the calling drops are cut out of circuit when speaking, ordinary low-resistance (100 ohms) 2-coil drops are

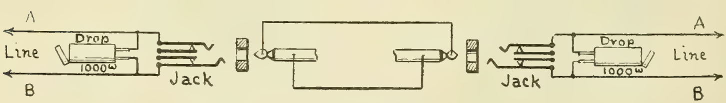


Fig. 201

used. As with the single-cord board, a telephone set provided with a single 2-point plug is used for operating.

Another plan of working double-cord boards is to join the drop coils to the two outer springs of the jack, and use a single double-strand cord, with a 2-point plug joined to each end for connection. When lines are connected, both drops are then

left in shunt to the lines, and both fall when the clearing ring is given. In such an arrangement tubular drops of high resistance (1000 ohms) must be used.

Special Exchange Working.—When the double-cord boards are needed principally for exchange working, the exchange

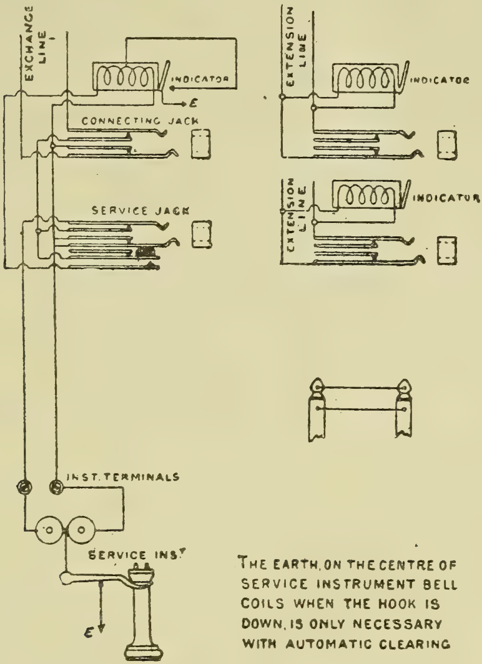


Fig 202

junction lines are furnished with special apparatus, and the working is modified. Two jacks (Fig. 202) are fitted for the exchange line, the upper one called the connecting-jack and the one below the service-jack. The connecting-jack is a 4 or 5-point break-jack, to the outer springs of which the exchange line is connected. The service-jack is a 7-point

jack, with its ordinary long working springs connected to the service instrument.

It will be seen that the indicator coil is disconnected until a plug is inserted in the service-jack, the service instrument being at the same time disconnected from the exchange line. A 2-way cord with plug at each end is used for connecting. The other lines, called extension lines, are joined up as shown on the right of the figure, each with a tubular drop permanently connected across the loop, to serve as clearing drop. The bell of the service instrument rings if the exchange calls, and the operator answers at once. To connect another line to service instrument, one plug is inserted in the service-jack and the other in the jack of the line required or calling, and to connect the latter to the exchange line the plug is taken out of the service-jack and put in the exchange connecting-jack. The object of the exchange indicator is to provide for a call coming from the exchange whilst the operator is answering a call from some of the other lines. As shown in the figure, the drop is so arranged that when the shutter falls an earth connection is made to the centre point of the coil. This, however, is only needed for some special automatic clearing systems.

Mixed Service Boards.—With these small boards it is frequently the case that some of the lines served are purely private, and are not allowed connection through to the main exchange. In order to prevent the possibility of such connection, and yet allow other of the lines to be connected to either exchange or private lines, certain alterations are made in the connections of the jacks and plugs.

Fig. 203 shows the nature of these alterations as made to a 5-line single-cord board. The service plug, it will be seen, is 3-point with a 2-way cord. The exchange line (first on left hand) is fitted with 3-point plug, and the bush and tip spring of the jack are connected together. The next two lines (Nos. 2 and 3) have exchange facilities, and they also have 3-point plugs, but no alterations are made in their jacks. Nos. 4 and 5 are not allowed to go through to the exchange,

and are fitted with 2-point plugs, and the bush and longest spring are joined together. It results from these connections that the service instrument and Nos. 1, 2, and 3 lines can be connected to any other lines, but Nos. 4 and 5 can only be connected to Nos. 2 and 3; for if one is connected by its own plug to No. 1 (the exchange line) it would be short-circuited, as the long spring and bush will be connected by

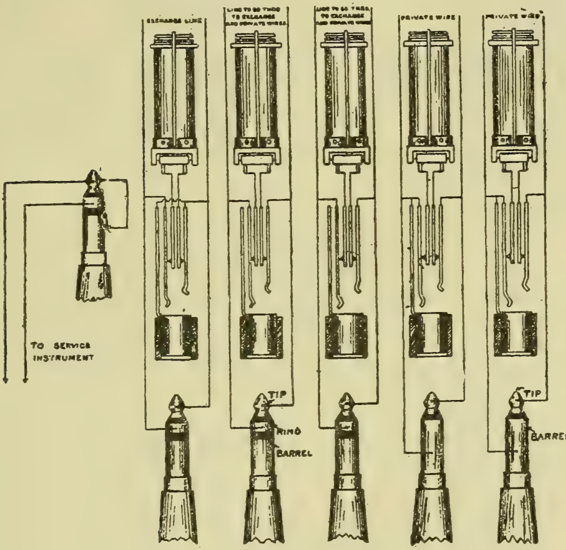


Fig. 203

the sleeve of the plug, and the tip spring is already connected to the bush. A similar effect is produced if the exchange plug is inserted in a private line-jack (Nos. 4 and 5).

Double-cord boards may also be arranged for mixed service. 3-point plugs and cords are then used, the short or tip spring of exchange line connecting-jack, Fig. 202, is joined to the bush, and the bushes of the jacks of prohibited lines are joined to the long or sleeve springs of their jacks.

Small Switch-Boards for Central Battery Sub-Exchanges.—

Small switch-boards are often needed for sub-exchanges of an unimportant nature working in conjunction with a main central battery exchange. In such cases the method to be adopted for the supply of the necessary speaking current to the extension lines has occasioned much thought. If the extension lines were always connected through to the main exchange the matter would be comparatively simple, as the

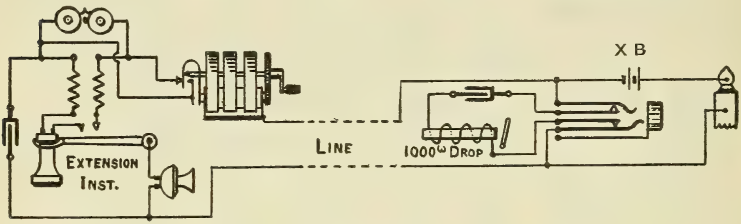


Fig. 204

current could be supplied to the extension instruments through the junction lines. It is, however, necessary to provide also for the extension lines being connected one to another. The provision of storage cells in such cases is out of the question, for many reasons. For such cases current has been fed from the main exchange battery through special feeder lines run for the purpose. The simplest and most satisfactory plan has

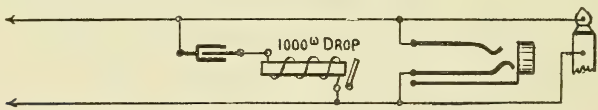


Fig. 205

been to provide a small battery of dry cells in each extension-line cord circuit of a single-cord board, as shown in Fig. 204, the battery of two cells being included in the tip-conductor circuit, as shown at X B. It will be noticed that a condenser is included in the indicator circuit, and a magneto-generator is attached to the extension instrument for signalling purposes.

Fig. 205 shows the connections of the exchange junction

line, and Fig. 206 those of the "service" or "main" instrument attached to the switch-board, to which a generator is screwed for calling the extension lines.

When two extension lines are connected together the

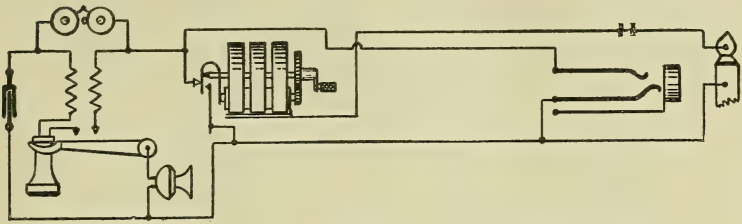


Fig. 206

speaking current is supplied from that battery which is connected to the connecting cord used for joining the lines, the battery connected to the second line being disconnected. If an extension line is connected through to the main exchange the cord in connection with the junction line is used for making the connection, and the speaking current for the extension instrument is supplied from the central battery.

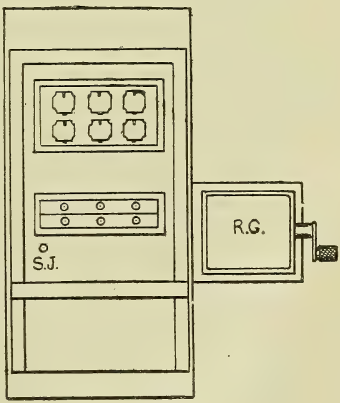
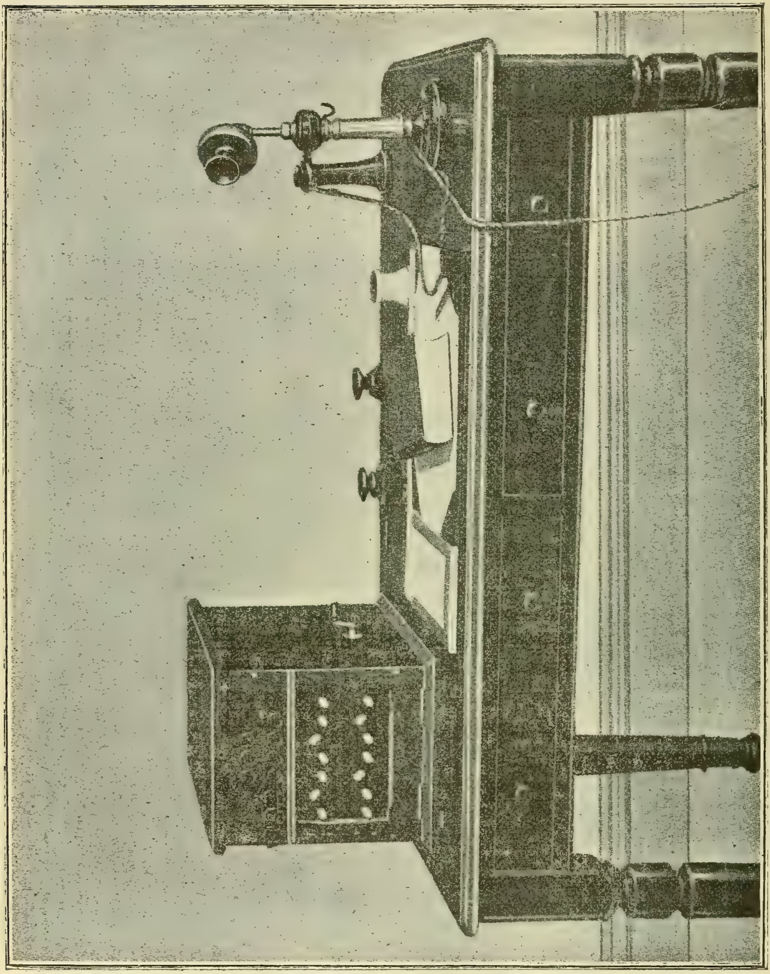


Fig. 207

Fig. 207 is an outline sketch of a 6-line board, with the ringing generator R G screwed to the side. The board is similar to that shown in Fig. 197, and is operated in a somewhat similar manner. The service instrument jack S J is fitted below the other jacks. The main exchange is signalled by inserting the service plug into the junction-jack (or *vice versâ*) and raising the receiver.

C.B. Cordless and Plugless Boards.—Fig. 208 shows a very



convenient type of small switch-board used for C.B. private branch extensions. It is intended to stand on a desk or a table,

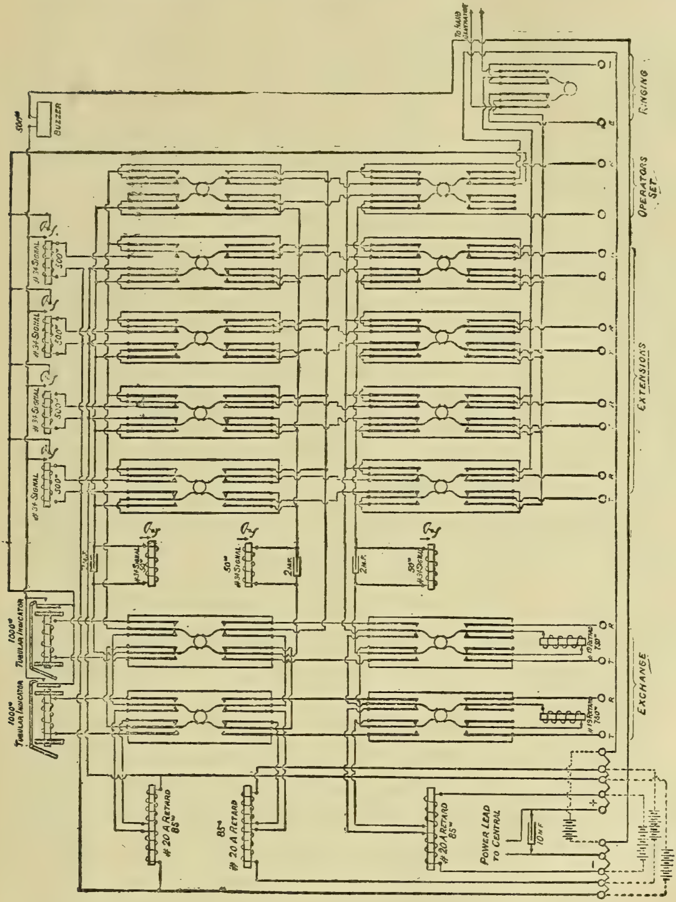


Fig. 209.—C.B. Cordless Switch-board

thus allowing the attendant to carry on clerical work, and yet be always ready to answer a call, and thus ensure more prompt attention than is met with, with ordinary wall sets.

The instrument shown is a six-line board, intended for two exchange lines and four extensions; similar instruments are made for four lines (one exchange and three extensions) and for ten lines (three exchange and seven extensions). The calling indicators for the exchange lines are 1000^w tubular (as shown on the left of the second row), and those for the extensions are 500^w "eye-ball" signals, shown in the same row.

Two rows of keys, similar to combined ringing and listening keys, are used for making the connections, the upper positions and the lower positions of the upper row of keys being used for this purpose, whilst the lower position of the lower row is used for signalling—by generator in the case of the extensions, and by connecting a 750^w-retardation coil across the loop for the exchange lines.

Any keys in any row moved to the same position are connected together, as will be seen from Fig. 209, which shows the full connections. In Fig. 208, Nos. 2 and 5 lines are connected by the upper row of keys, and Nos. 3 and 6 lines in the lower row of keys.

The right-hand keys in each of the two rows are used for answering purposes, the call being made at the extension instrument by lifting the receiver.

The three eye-ball signals on the upper row are the clearing indicators, they are connected directly in series in one leg of the loop, but are shunted with a two-microfarad condenser for speaking purposes.

When local batteries are used for working instead of power leads, four separate batteries (of three 6-cells and one 4-cells), are used, connected, as shown by the dotted lines in the left-hand lower corner of Fig. 209, the terminals marked + and − being then unlooped from each other.

CHAPTER XIII

LARGER SUB-EXCHANGE AND PRIVATE BRANCH EXCHANGE SWITCH-BOARDS

The switch-boards so far described have been intended to supply the wants of small central offices or private exchanges of not more than about 25 lines, where the calls are not continuous, and an operator is not required to be constantly in attendance. For exchanges of more than this number, and up to about 300 lines, a different form of board is required, in

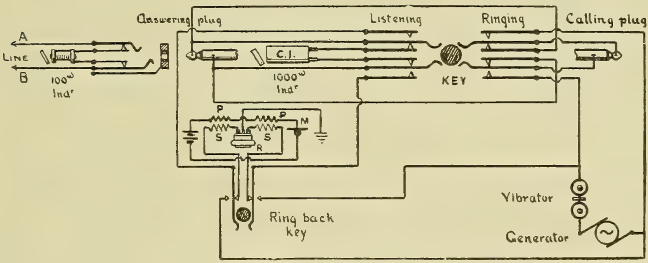


Fig. 210

which special provision is made for rapid operating and for the effective supervision of the connections.

"*Standard*" *Board.*—Figs. 212 and 213 give views of a 50-line switch-board (arranged for magneto working) as used by the National Telephone Co. It is worked on the double-cord principle, the cords and plugs being quite distinct from the line connection until the plugs are inserted into the line-jacks, as shown in Fig. 210. Each pair of cords is provided with a tubular drop of 1000 ohms resistance, connected in

bridge or shunt, for clearing signals, and with a combined ringing and listening key, as per Fig. 180 or Fig. 182.

The subscribers' lines are brought through a hole in the top of the board, and are soldered to tabs at the back, these tabs being arranged in numbered pairs (or sometimes threes, one being left spare for multiple use when the number of boards has increased beyond three or four). From the tabs which extend through the board, as shown, wires connect to the line springs of the 5-point jacks, arranged in rows of ten, and from the short springs of the jacks wires connect to the 2-coil indicators (100 ohms), also arranged in rows of ten.

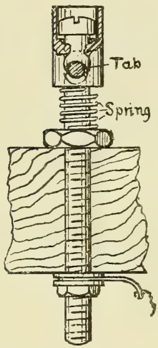


Fig. 211.—Scale $\frac{2}{3}$

The connections of a subscriber's line, and those of the operator's circuit and connecting cords, are shown in Fig. 210.

Plug Shelf.—Through holes in the top shelf of the board a number of pairs of connecting cords are threaded, in two rows, the attached plugs resting in recesses when not in use. The plugs in the back row are the "answering" plugs, and those in the front row the "calling" plugs.

Key Shelf.—On the "Key Shelf," below the indicator panels, a corresponding number of combined listening and ringing keys are arranged in line with the plugs and cords, both sets being correspondingly numbered as a guide. The conductors of the cords are soldered to "tabs," which are clamped to spring "cord fasteners" fixed on a shelf at the back of the board. (A view of one of these "fasteners" in part section is shown in Fig. 211.) Each of the cords is drawn straight, and kept taut by a brass pulley, to which is attached a lead weight.

The cords and plugs used on boards on which 5-point subscribers' jacks are used, need only be of 2-way type, but generally 3-way cords and plugs are used, so as to enable the boards to be joined up for multiple working when there are four or more in one centre. If 7-point jacks are used in the

board, 2-way plugs and cords only are needed. For possible future multiple working of the boards it is also usual to employ an operator's set which is differentially wound, and which has the centre point of the receiver connected to earth (as shown at R of Fig. 210), to provide an "engaged test," as explained in the next chapter.

Operation.—On the sub-station ringing, the drop D is actuated. The operator inserts answering plug into the jack, and presses listening key, so that the round wedge forces out the long left-hand springs, and thus connects her telephone set to the calling line. On ascertaining the number wanted, she inserts the calling plug into the jack of that number, and turns her key to the ringing position for a few moments. The ringing vibrator shows if current is passing from the generator.

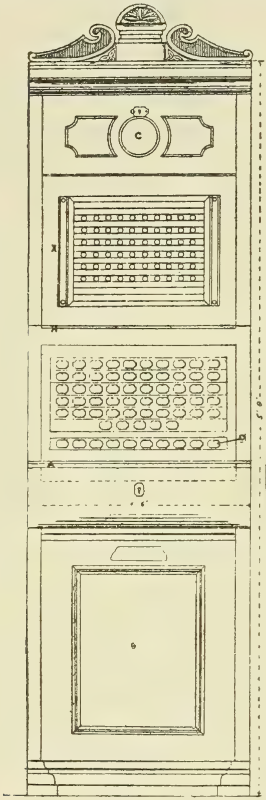
Ring-Back Key.—In case it should be necessary to ring the "calling" subscriber, a single ringing key is specially provided common to each board. Before this can be used, however, the proper listening key must be in the speaking position.

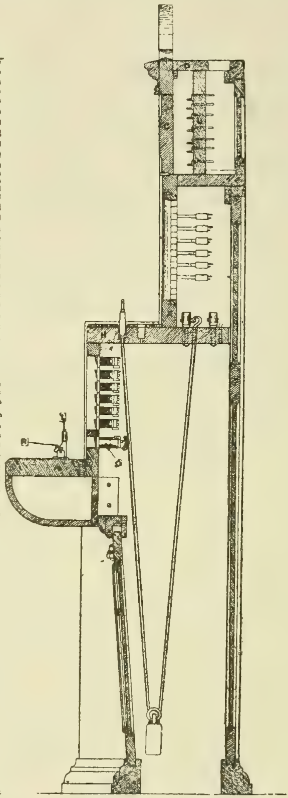
Clearing.—When finished, the subscribers give the clearing signal, which drops the "clearing indicator" C.I., and the operator restores to the normal condition.

Private Branch Exchange Switch-Boards with C.B. Working.—It is thought desirable at this point to give the following descriptions of a branch of common battery switch-board working, but it may be necessary that Chapters XVI. and XVII. shall be first read over before the diagrams, etc., can be thoroughly comprehended by those not familiar with common-battery working.

When a small exchange of, say, from 25 to 150 lines is worked in conjunction with a main common battery exchange, several modifications of the connections for boards for magneto working are required. Such exchanges are too small to allow of the provision of a power plant for the necessary current, and arrangements are in such cases made so as to utilise, as far as possible, a supply of current from the main exchange.

When lines are joined through to the main exchange, the necessary current for C.B. speaking is furnished to the sub-exchange subscriber's instrument through the junction line





ELEVATION — SECTION

Fig. 212 Scale $\frac{1}{16}$ Fig. 213

which joins to the main exchange. For the working of the supervisory and calling signals, and for supplying speaking current to lines not connected through to the "main," one or more pairs of "power leads" are run between the "main"

and "branch" exchanges. The number of such pairs depends on the distance, the number of working lines, and the amount of traffic on the lines in the "branch." Two sizes of copper wire are used for the leads—viz., Nos. 20 and 22 S.W.G. As an example we may take a "branch" exchange at a distance of 500 yards from the "main." For this 1 pair of No. 20 wires would be sufficient for a traffic equal to a maximum of 5 connecting-cord circuits in use at the same time, and 2 pairs for a maximum up to 10 cord circuits. These leads are connected to "bus bars," as shown in Figs. 214 and 215.

Line Connections.—Fig. 214 shows the line connections of

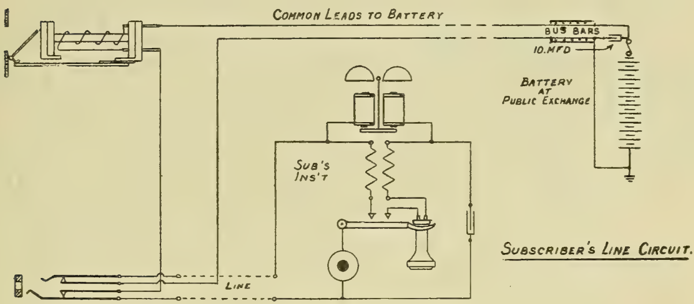


Fig. 214

the sub-exchange lines. As lamp signals with the necessary relays would require more current than could be economically furnished through the supply leads, it is the practice to use some form of self-restoring annunciator, such as the "eyeball," Fig. 164, which is fixed in a vertical position, or the "visual signal," Fig. 166A, which is fixed in a horizontal position, such as on the cord shelf, where it can be directly associated with the cords. These annunciators show while the current is on the line and are visible while talking is going on, and disappear when the current ceases,—viz. when the receivers are hung up—so that the signal for clearing is a negative one, the disc disappearing when this is to be done.

Cord Circuit.—Fig. 215 shows the connecting cord and operator's connections, and it will be seen that when two sub-exchange lines are connected together by the two plugs, the speaking current is supplied from the bus bars, through two contacts of a cut-off relay, C.O.R., and a double-wound retardation coil, R.C. Two independent clearing visual signals are inserted in the tip conductor of the cords,* these

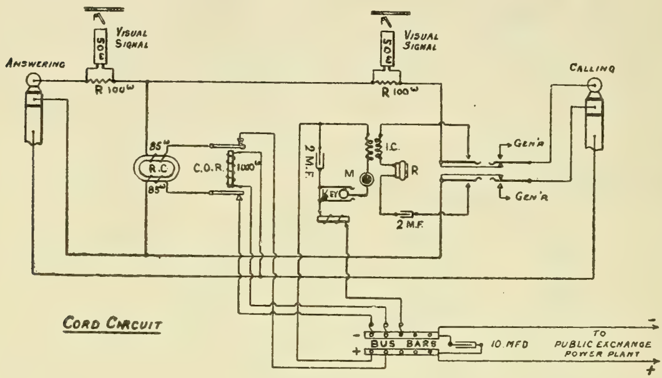


Fig. 215

annunciators being shunted by non-inductive resistances, R.R., so as not to interfere with the speaking.

Junction-Line Connections.—Fig. 216 shows the connections of a "junction" line joining the sub-exchange to the "main" exchange, and it will be seen that each "junction" is furnished with two jacks at the sub-exchange, one of which (a 7-point) is used in the day-time, when an operator is in constant attendance, and the other (a 5-point) at night, when it is required to leave one of the sub-exchange lines plugged through to the main exchange. When the "day" jack is used a 600-ohm retardation coil becomes connected as a shunt across the line; the purpose of this is to complete the circuit for the supervisory signals at the "main," so that the operator there will not be troubled by her supervisory lamp remaining lit un-

* In the latest practice these signals are inserted in the ring conductor.

til the called-for sub-exchange subscriber answers, the control of the sub-exchange connection being left entirely to the sub-exchange operator. During the night an operator is seldom kept in attendance, and it is often required to leave some line or instrument plugged permanently through to the "main," in which case it is necessary for the "main" operator to see the call through, so that the extra retardation coil is not required, the supervisory lamp remaining lit at the

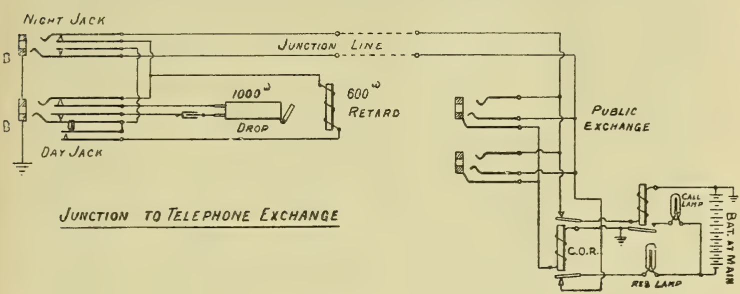


Fig. 216

"main" until the called sub-exchange subscriber answers the call.

When a sub-exchange line is connected to the "main," the third or sleeve conductor of the connecting cord, Fig. 215, becomes connected to earth through the bush of the junction-jack B B, Fig. 216. This closes a circuit from the negative, bus bar, through the coil of the cut-off relay, C.O.R., Fig. 216, the sleeve conductor of the cord, bush of junction-jack, and back by earth to the positive pole of the battery. This causes the energising of the relay and the breaking of its contacts so that the local battery feed from the bus bars is cut off the connecting cord, the working speaking current being supplied then directly through the junction line. The sockets of the ordinary lines have no earth connection. See Fig. 214.

CHAPTER XIV

MULTIPLE SWITCH-BOARDS—MAGNETO SERIES

In a large telephonic exchange, where more than three or four " standard " switch-boards similar to those described in the last chapter are employed, the connection of the " called-for " subscriber's line, if his jack is out of the reach of the operator who answers the call, gives rise to much trouble and delay. Some means of communicating between the operators on different tables has to be adopted, and whichever way this communication is accomplished, time and trouble are expended, the connection is delayed, and the risk of connecting wrong numbers is greatly increased.

To overcome these difficulties, the *multiple* switch-board was invented by Mr C. E. Scribner in America in 1880, and independently by Mr F. B. O. Hawes in this country very shortly after. The principle of this board is that, instead of having to connect any one subscriber's line at some one invariable position on the switch-board, as with the ordinary form of switch-board, the multiple board enables a connection to be made to any one line at as many different points as there are *sections* of the board. This is accomplished by multiplying the number of spring-jacks belonging to each line—hence the name *multiple*—and fitting these "multiple-jacks" at regular intervals along the switch-board, so that at least one can be reached from any one operating position, and so enabling any operator to connect any two lines together without moving from her position. By such means the number of operations is reduced by about one-half, and the troubles mentioned above are avoided.

Many forms of multiple switch-board have been invented

and brought into use. They are all made up of a number of separate boards or *sections*, varying in length from about 5 feet to about 6½ feet, these being fitted end to end, so that they extend in a long straight or curved line to make a complete board.

Each section was fitted with a jack *for every subscriber's line* in the exchange, and with a certain number of calling annunciators, this number varying from about 150 to 300 according to the amount of traffic over the lines whose *calls* have to be exclusively attended to by the operators on that section.

Each section is also fitted with connecting and supervisory apparatus for the operators, including ringing and listening keys, clearing annunciators, plugs and cords. These are arranged in sets of about fifteen to eighteen for each operator, and there are usually three sets to each section. Each section is also fitted with a number of jacks and keys for special services, such as for *junction* lines for connection to other exchanges in the same town or centre, or for *trunk* lines for connection to other towns.

Engaged Test.—As in a multiple board any line may be connected at any section, it is evident that before connecting a line at any one section some means must be provided for ascertaining if the line is already connected at some other section, or it may happen that a line might be connected to other lines at several sections at the same time, and so lead to trouble and confusion. An *engaged test* is, therefore, a necessity in any multiple system.

A special clearing annunciator is used in connection with the plugs and cords, and as there is only one calling annunciator to a line, but connecting-jacks at many points, it is evident that the calling annunciator must be prevented from operating whenever a connection is made to the line, or much confusion would result. This is accomplished, as we shall see, by using *break-jacks* in what are called the "*series*" multiple boards, and in the *branching* system boards by using self-restoring annunciators and by a local battery

current connected when the plug is inserted in a jack, preventing the annunciator from operating while the line is connected. In the now more general "central energy" systems the same object is attained by using a *cut-off* relay to sever the connection of the common annunciator or relay by a current connected when the plug is inserted in a jack.

Series Multiple Board.—Figs. 217 and 218 give a section and front view of one section of a board with ordinary drops and break-jacks. It will be seen that the upper portion of the section is divided into six panels. In these six panels is fitted a spring-jack for each subscriber whose wire is centred in the switch-room. The jacks are arranged in groups of 100, made up of five horizontal rows of 20. Each group is numbered from 1 to 100, or from 0 to 99, a number on the framework of the panels or on a special strip which can be attached to the framework denoting the particular hundred. The first group (the bottom left-hand one) is numbered 0, the next to the right 1, the next 2, and so on to the sixth panel; then another row above from left to right, thus building upward. These groups are called the *multiple* jacks, to distinguish from the *local* jacks arranged along the length of the section just below. The "local," or "answering," or "home" spring-jacks are those into which the operators plug in answering the calls of the subscribers whose wires terminate on the section. They correspond to the jacks in the "Standard" switch-board described in last chapter; in fact, the multiple

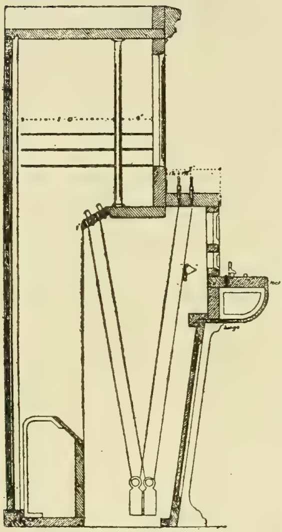


Fig. 217.—Scale $\frac{1}{24}$

board may be looked upon as a collection of Standard boards, with the addition of the multiple-jacks and provision for engaged testing.

The indicator drops in connection with the local-jacks are arranged at a lower level, in four groups of 50, making 200 in all, which is the number of subscribers whose lines are

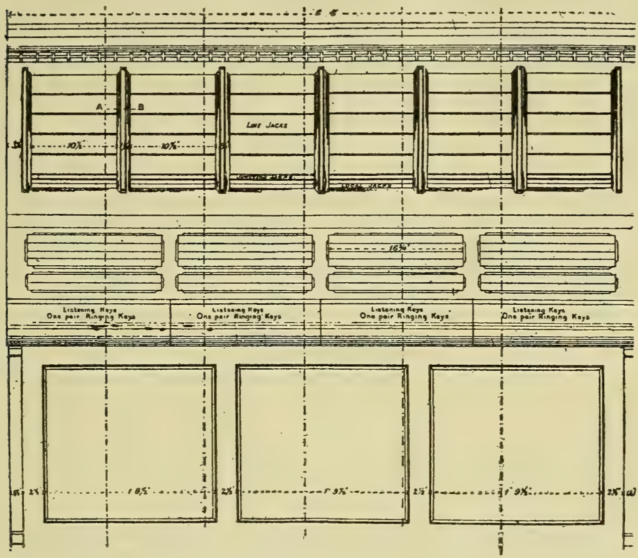


Fig. 218.—Scale $\frac{1}{24}$

terminated on each section of this board, and whose calls are answered by the operators attending on this particular section.

Between the local-jacks and the drops a ledge or shelf is formed, through holes in which the connecting cords pass, the plugs attached to them resting when not in use in recesses bored in the shelf, as in the Standard. The cords are arranged in pairs, one in front of the other. Connected to, and in a vertical line beneath each pair, is a ring-off drop, fixed below the calling drops. On another shelf, just below,

a listening and ringing key is provided for each of the forty-five pairs of cords. This division of the keys from the corresponding cords, etc., is a bad feature which in later switchboards has been avoided. The cords and accessories are arranged in three groups of about 15 for each of the operators who attend.

In order to make a complete board, as many sections are joined together end to end as there are multiples of the subscribers' lines attended to on each section in the exchange, with the addition usually of other special sections for the purpose of working the trunk, junction, and other special lines or local services, and with sufficient spare spaces or

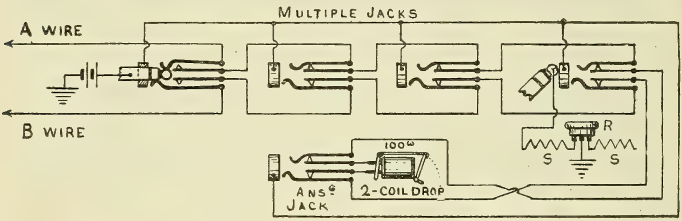


Fig. 219

sections to allow for expansion during the next three or four years.

Line Connections.—Fig. 219 gives the connections of a subscriber's line, showing the method in which the multiple and local-jacks are connected, and the engaged test obtained. From the test-room the wires of each line are connected to the long springs of its proper 5-point multiple-jack on the first section, the A wire being connected to the "tip" spring, and the B wire to the longer "sleeve" or "ring" spring. From the short inner springs of the jack connections are made to the long springs of the similarly numbered jack in the next section of the board, and so on to the multiple-jack on the last section, from the short springs of which connection is carried back to the long springs of the corresponding "local," "home," or "answering" jack on the section on which the calling drops

are fitted, these drops being connected to the short springs of the answering jack.

Test Wire.—The sockets or bushes of the jacks of a line are all permanently connected together by what is called the "test" or "click" wire.

Operators' Connections.—As shown in Fig. 220, these are similar to those of the Standard board, except that 3-point plugs and 3-conductor cords are used, the third conductor of the latter being connected to the sleeve or barrel of the plugs, and also to one pole of an earthed battery, as shown. The centre point of the operator's receiver is also connected

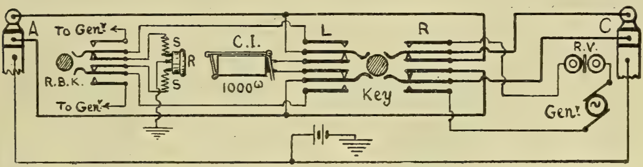


Fig. 220

to earth. These additional arrangements are needed for the engaged test.

In Fig. 219, a plug is shown inserted in the first jack, and this, it will be seen, cuts off all connection with the line springs of the other jacks farther down the board, and also with the calling drop.

By contact with the sleeve of the 3-way plug the bush of the first jack is connected to the earthed test battery, and the "click" wire connects all the bushes of the other jacks also to the test battery, so that, if the tip of another plug is touched against any one of the jacks of the same line on another section, the operator will hear a click in her receiver, owing to the test battery finding a circuit to earth through the centre point of the operator's receiver coils, as shown at the fourth jack in Fig. 219. An operator getting a click on touching the bush of a jack at once knows that the line of that number is engaged on some other section. There are

other methods of making the engaged test, but the above is probably the most common.

Fig. 221 shows how the engaged test can be arranged when using 7-point break-jacks and 2-way plugs and cords. The operator's connections will then be the same as with the Standard board, Fig. 214, the centre point of the operator's receiver being earthed, as there shown.

When the plug is inserted in a jack, the extra spring is pressed against the metal stud, which, with the similar studs of the other jacks of the same line, is connected by "click" wire with an earthed battery. This contact connects all the bushes of the idle jacks of the same number to the test battery,

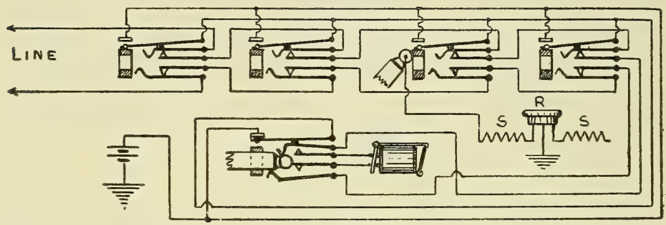


Fig. 221

and a click is obtained when the test is made, in the same manner as before shown. This is not such a good plan as the first one described, as the 7-point jacks are more complicated, and more liable to get out of order, and the test battery has to be connected to all the test wires. On the other hand, the first method necessitates the use of 3-way plugs and cords, which are also more liable to give trouble than the 2-way. However, the plugs are not so numerous as the jacks, and faults on them are more easily rectified.

Cabling or Wiring.—The great number of connections that have to be made to the jacks necessitates the adoption of some definite plan of dealing with the mass of wires in order to avoid confusion. The number of wire connections increases as the square of the number of lines in the centre, so that a

compact method of joining up the jacks and carrying the wires is especially necessary in a large exchange.

The method of wiring adopted should allow of the jacks being readily accessible in case of faults.

The shorter the length of wire used the better, both on account of lower cost and because the static capacity of the cable is rather high.

The wires used should not impede access to other parts of the board, and they should occupy as little space as possible consistent with other requirements.

These requirements are best met in what is called the "straight" or "flat" method of cabling.

Cables.—These are flat in section, as shown in Fig. 224, about

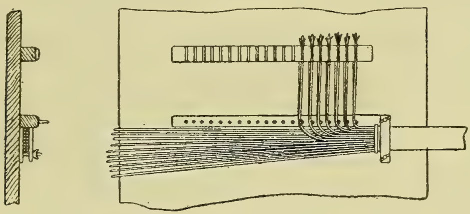


Fig. 222

$1\frac{1}{8}$ inches wide by $\frac{5}{16}$ths of an inch thick, each containing 63 wires, made up in 21 sets of three, each set being twisted and kept together by a few cotton threads. One wire of each set is used for the A line, one for the B line, and the third for the test line. All the B wires are coloured green, and all the test wires brown, but each of the A wires is distinguished by a distinctive coloured covering, so that any one set can be identified by the colouring of the A wire. The wires used are No. 22 S.W.G. tinned copper, with two coverings of cotton saturated with paraffin. The resistance of the wire is about 73 ohms per mile.

This cable provides for a strip of 20 jacks, with a spare set to replace should any of the wires prove faulty.

*Cable Forming.**—The lengths of cable for each 20 lines

* See also p. 202.

are so connected to the jacks, and bound up together, from one end of the board to the other, that they look like a single straight cable with strips of jacks fastened at regular intervals (equal to the width of a section). The fitting to the jacks is done apart from the switch-board on a long bench fitted with *forming blocks*, one of which is shown in Fig. 222 and Fig. 223 (the latter shows the block complete with a strip of old-pattern 3-point jacks), fixed at distances apart equal to the width of the sections of the board. In this manner the joints can be more carefully soldered and inspected than if they had to be done in position behind the tables, which was the case with an earlier system of cabling. It is now usual for this cabling work to be done at a manufactory, and the "formed" cable sent to the exchange with the jacks fitted, and all ready for placing in position on the boards. To prevent misfits in such cases it is necessary to furnish very accurate particulars of the dimensions, etc.

The *forming block*, Fig. 223, is made up of a block of wood, D (fixed to the bench), to which the strip of jacks is temporarily screwed. F F is a smaller wooden block, from the top of which 20 small iron pins project, round which the wires are bent in connecting to the jacks. The lengths of cables (which are a certain amount longer than the length of the switch-board sections), while being connected to the jacks, are fixed in the clamps shown, a length of cable coming from each side. Testing for the proper wires is done by means of plugs and cords connected to a battery and bell, so that the bell sounds when the same wire is touched by a plug at each end.

When a whole length has thus been connected, soldered, and tested, and the wires bound up as shown, it is released from the forming blocks, lifted off the pegs in F F, carried to its position behind the boards, and the jacks fixed in their proper places. Fig. 224 gives a section of the cables required for fitting up a board of 600 lines, being 30 cables for 30 strips of jacks, showing a section of a block of 100 jacks, and the manner in which the cables are supported when in position.

Fig. 225 shows how the cables are arranged one behind the

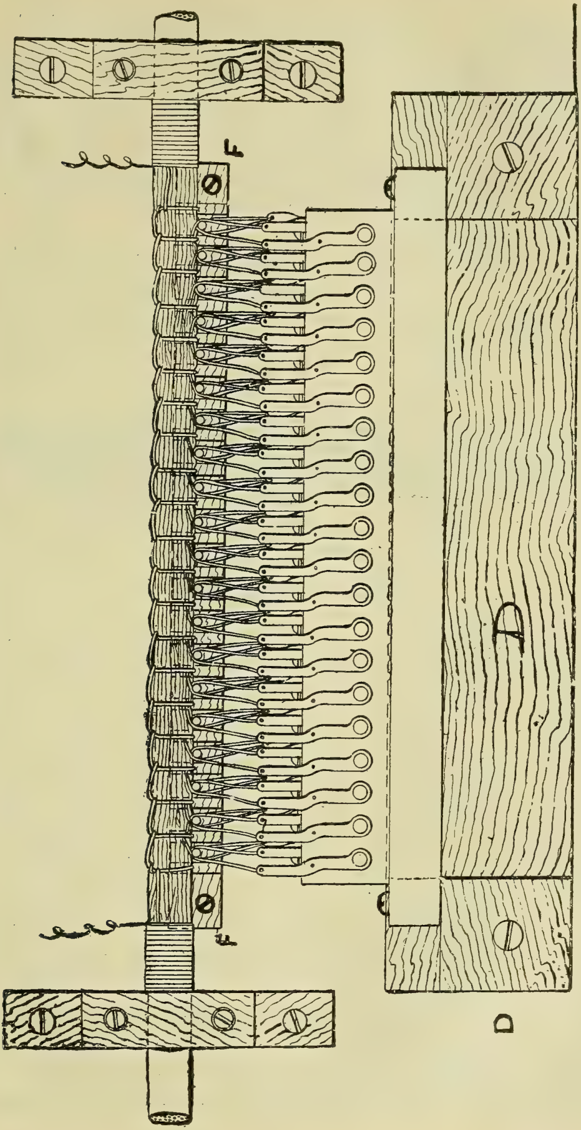


Fig. 223

other by making the parts of the connecting wires from the cables to the rows of jacks in six different lengths, differing from each other by the width of the cable. By this method the cables are very compactly arranged, the shortest possible length of cable is used, access to the other parts of the switchboard is not impeded in the least, and the strips of jacks can be brought out behind for inspection and the remedying of faults.

The above describes the method of wiring the multiple-jacks only, but it is afterwards necessary to join up the "local" or "answering" jacks fitted on the sections which contain also the corresponding calling drops. For this purpose a length of

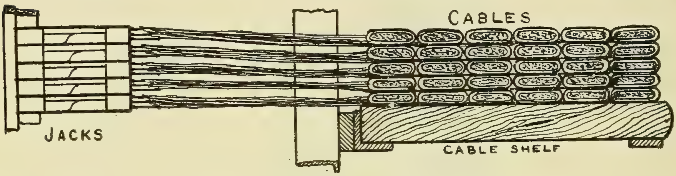


Fig. 224.—Scale ¼

cable sufficient to reach to the proper section is connected to the last multiple-jack strip, allowance being made for sufficient spare to serve for additional sections to be added when the fitted sections are filled up, otherwise the cable would have to be spliced when these were added. When such additional sections are added, the cables are cut, leaving attached to the multiple-jacks a sufficient length to reach to the corresponding jacks on the first added section. The other end of the cut cable is connected to the corresponding jacks on the last of the added sections. These "return" cables are usually carried in a trough laid on the floor and extending the full length of the board. The number of cables in this trough gradually diminishes as they approach the first section.

A modification of the method of connecting the cables on to the multiple-jacks is now often used, in which, at each strip of jacks, the cable coming from the right hand is formed and

tied up independently of the cable coming from the left. In this manner more flexibility is obtained, and the jacks can be more easily taken out for examination in case of faults, or for cleaning.

Jack Fasteners.—These are used to fasten the jack-strips in position, and are of the shape shown in Fig. 226. They are made up of a circular plate out of which a quadrant has been cut, fitted with a screw shank, which passes through a hole in the steel framing of the switch-board. The fastener clamps four jack-strips, being fitted at the point where the four corners meet. By means of a slot in the end of the shank, the plate can be turned from the front, and a corner of a strip is released when the fastener is turned so that the open quadrant corresponds with it.

Cable Lifting.—When a strip of jacks is required to be brought out behind for inspection or repairs, the body of cables which lie above the cable connected to the strip are lifted up by wedges, etc., the jack- fas-

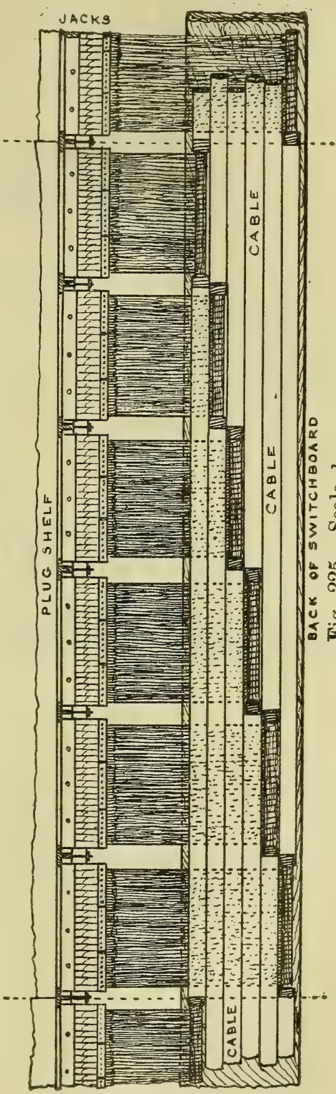


Fig. 225.—Scale $\frac{1}{12}$

teners turned to release the strip, and it can then be drawn out behind. In a large exchange the weight of cable to be lifted may be very great, and a special "cable lifter" is then used for the purpose. This consists of an upright

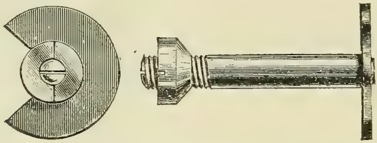


Fig. 226—Full size

frame shaped to fit against the back of the switch-board and furnished with an upright screw, which, on being turned by bevel gearing driven by a handle, lifts up a long steel wedge placed between the cables and connected to a sliding box-nut fitted on the screw.

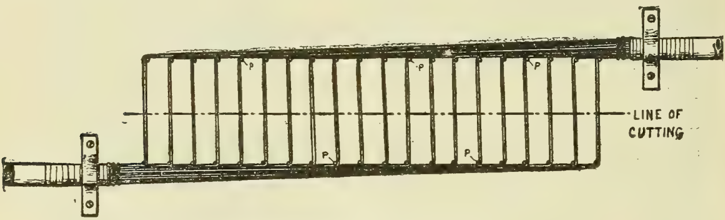


Fig. 226*a*.—Cable Forming

Cable Forming.—In order to prevent waste of cable in cutting off the lengths required for fitting it is now usual to form for cutting in the manner shown in Fig. 226*a*. By adopting this method the waste is reduced to a minimum.

Note.—For cost of multiple switch-boards see Appendix.

CHAPTER XV

MULTIPLE SWITCH-BOARDS—MAGNETO-BRANCHING

Branching Multiple System.—This system, introduced by the Western Electric Co., was the first of the "branching" systems which have now become almost universal. Although this form is not now much used, it is thought well to describe it, as it illustrates the principles and shows the difficulties encountered in the branching systems.

The name "branching" comes from the fact that the multiple-jacks of any one line are all connected as branches from the line wires, which may run continuously from end

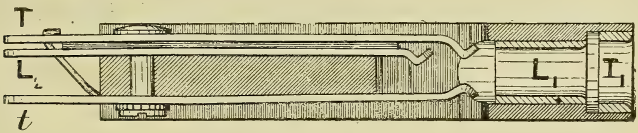


Fig. 227—Full size

to end of the board, instead of passing in series through the contacts of the jacks, as in the "series" system.

The jacks used are of a peculiar form, as shown in section in Fig. 227. They differ from the ordinary branching-jacks in having two springs, T and *t*, of the same length, and in having a large brass test bush or collar, T, fitted in front of the ordinary bush. T and T are connected together.

The plug used is similar to the 3-way plug, but the ring is not furnished with any connection to the body of the plug.

Line Connections.—Fig. 228 shows the connections of the line and test wires to the jacks, and also to the self-restoring drop shown in Figs. 161 and 162, and already described in

Chapter X. It will be seen that the coil O of the drop is permanently joined to the line wires, and that the test wire is connected to the restoring coil R, and through that to an

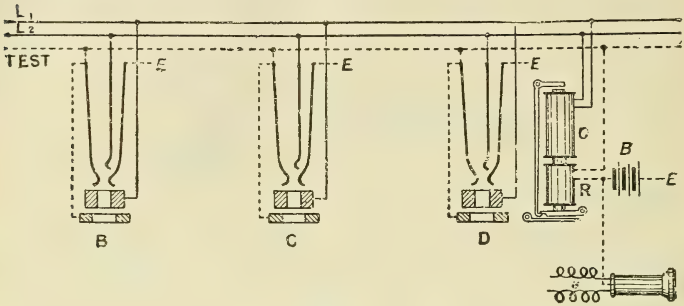


Fig. 228

earthed battery, B, this being also connected to the centre of the operator's receiver coils.

On the insertion of a plug into a jack, the springs T and *t* are connected together by the collar T of the plug, so that

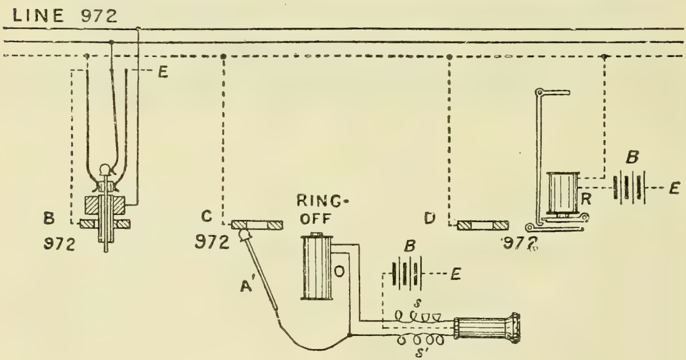


Fig. 229

the test wire and all the bushes T of that number are thereby connected to earth, and will give the test click in the operator's receiver when the tip of the plug is touched on to it, as shown in Fig. 229. As previously mentioned, it is necessary to lock

the line indicators, and prevent their falling while the line is connected, and Fig. 229 also shows how this is accomplished by means of the test battery B.

Special ring-off drops are provided as usual, and these are

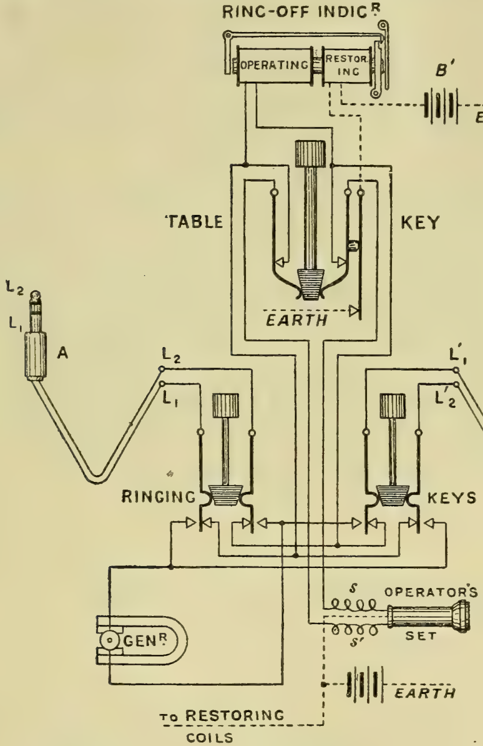


Fig. 230

also of the self-restoring type, as shown in Fig. 230, which gives the cord connections, old-pattern separate ringing and speaking keys being shown. There will thus be three drop coils connected as shunts when two lines are connected to each other, but as these are of high impedance they do not affect the speaking to any extent.

It will be evident that much of the operator's time will be saved by the use of this arrangement, and as it allows of the indicators being fixed high above the operators, more space is left within their reach for spring-jacks. The ultimate capacity of the boards may, therefore, be made larger. On the other hand the drops were in a bad position for observation and far removed from their corresponding answering jacks, which disadvantages and the greater advantages in connection with the relay and electric-lamp method of working have rendered the above system obsolete.

Cabling.—The wiring of the jacks is carried out in a similar manner to that described for the series board, except that two wires are connected to each soldering tab of the jacks—one for the cable to the right and the other for the cable to the left. The cables for the local jacks are, however, usually taken direct from the test-room instead of from the last multiple section; in fact, with a branching multiple system, the connecting cable wires may be carried in any manner which is most convenient or which will necessitate the shortest length of cable.

CHAPTER XVI

PRINCIPLES OF COMMON-BATTERY OR CENTRAL-ENERGY WORKING

WITH the main object of reducing the cost of maintenance of the sub-station instruments in connection with exchanges, many devices were, from time to time, suggested whereby the local batteries and generators at those sub-stations might be dispensed with, but none of the arrangements proved to be of practical value before the year 1892. Since that date many methods have been adopted which have considerably reduced the apparatus required, the maintenance charges, and the trouble of the subscriber—the latter result following from the making of the necessary signalling quite automatic.

History.—In order to elucidate the subject, it is thought

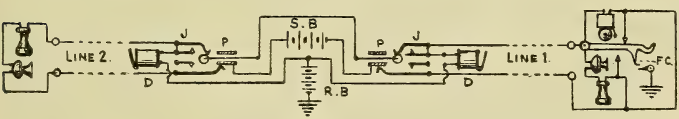


Fig. 231

desirable to give a short resumé of the progress of invention in connection with common-battery working.

Anders System.—The earliest suggestion of the kind was that patented in 1882 by G. L. Anders of London. His plan was to provide at the central office an earthed battery, R.B., Fig. 231, connected to all the subscribers' lines through their respective annunciators. At the sub-stations he arranged that when a receiver was lifted off the switch-hook the latter in rising made a temporary, or what is called a

"fleeting," contact, F.C., with an earth-connected spring, thus closing the circuit of the central battery, and giving passage to a current which operated the annunciator D. At the central office he also provided batteries, S.B., for speaking, one of which was included in the circuit of each pair of connecting cords; but a separate battery was required for each pair of cords, so that although it was *central*-battery working it was not *common*-battery. Fig. 231 shows the connections when two loop lines were joined by a pair of cords—the right side showing the signalling arrangements and the left side those for speaking. The clearing signal was given on hanging up the receiver, thus again giving the fleeting

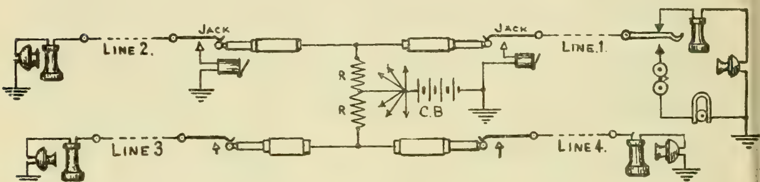


Fig. 232

earth contact, and causing the ordinary calling indicator to fall.

Bell System.—The next C.B. arrangement was by C. A. Bell in America, who suggested the connection of an earthed battery to the centre of every pair of connecting cords for the supply of current for speaking, as shown in Fig. 232. As this method would give rise to overhearing unless the battery were of very low internal resistance, he introduced a separate resistance coil, R R, between the battery and each pair of connecting cords to prevent or reduce it. This system was only arranged for single-wire and earth lines, but could have been applied to loop lines. The lines shown diverging from the positive pole of the battery represent connecting wires to other resistance coils and pairs of cords.

Western Electric Co.—In 1890 J. E. Kingsbury patented in

this country, on behalf of the Western Electric Co. of America, a C.B. method of signalling somewhat resembling that of Anders', except that the signal was made by pressing an earthing key at the sub-station, and that a condenser was interposed in one of the conductors of the connecting cords,

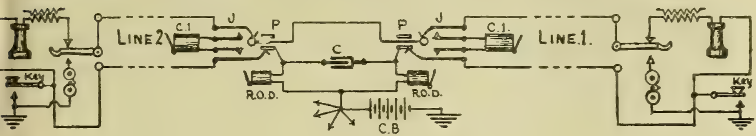


Fig. 233

this enabling the speaking currents to pass, but preventing the battery current. By this means independent clearing or ring-off signals could be obtained from ring-off drops, R.O.D., for each sub-station, as shown in Fig. 233. It will be noticed that special drops are used for clearing, altogether distinct from the calling indicators, C.I.

White.—In 1891 A. C. White patented in America a C.B.

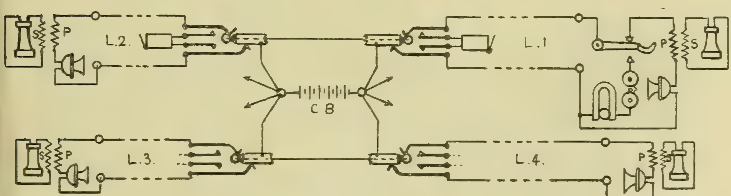


Fig. 234

system for speaking, which is shown in Fig. 234. It will be seen that the common battery, C.B., is included directly in each of the speaking circuits, being connected to the sleeve conductor of each of the connecting cords. The inventor pointed out that unless the battery was of extremely low internal resistance there would be overhearing between the

lines connected. He also suggested the use of an induction coil at the sub-station, with the low-resistance primary and the microphone in the line circuit, and the secondary and receiver in a local circuit, as shown in Fig. 234, thus reversing the usual arrangement.

Hayes System.—This system, patented in America in 1892 by H. V. Hayes, appears to be the first really practicable suggestion for the use of a common battery for both signalling and speaking. As shown on the right of Fig. 235 at C, a condenser is interposed in the bell circuit of the sub-station instrument. This cuts off the battery current, but allows the generator currents (or rather their energy) to pass when it is required to call the station, as already described

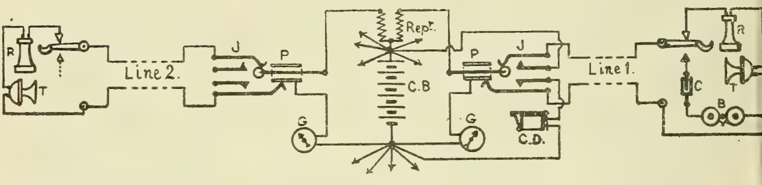


Fig. 235

in Chapter VII. On lifting the receiver, a complete circuit is formed for the C.B. current round the loop and through the annunciator or drop, C.D., at the exchange, and thus an automatic signal may be given. When two sub-stations were joined for speaking, the connections would be as shown in Fig. 235. The negative pole of the battery is shown connected to the sleeve conductor of a 2-way connecting cord with two independent clearing annunciators inserted, and the positive pole is connected through two coils of a repeater to the tip conductor of the cords. This arrangement gives a complete circuit to each sub-station, with the battery forming a common junction. Any speaking currents generated by, say, the transmitter at A, in passing through one coil of the repeater would by induction be repeated in the other equal coil, and in the circuit of B, including the receiver, or *vice versâ*. It is

necessary to provide a repeater for each pair of connecting cords. The repeaters prevent the leakage of speaking currents from one pair of connected subscribers to another pair, and also enable independent clearing signals to be provided for each sub-station.

As far as the central office arrangements are concerned, this system was the germ of what is now the most extensively used C.B. system—viz. that employed by the National Telephone Co. in this country and by the various Bell Telephone Companies in America. Instead, however, of a pair of repeater coils being connected on one side only of the battery, a pair of coils is connected on both sides of the battery—all the four coils being wound together on one core, and so forming a

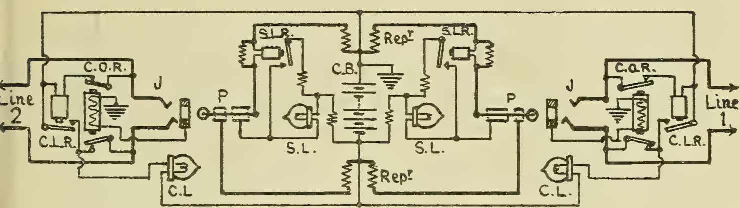


Fig. 236

single repeater or translator, with four equal windings, as shown in Fig. 236, which gives the connections of a more modern C.B. system, where relays replace the calling and supervisory drops or annunciators. These relays, when operated, cause the lighting of the calling (C.L.) and supervisory (S.L.) lamps, as already mentioned. The cut-off relays, C.O.R., serve the purpose of cutting out the calling lamps when connected for speaking, as described in Chapter XIV. As the relays, C.O.R., are in the direct speaking circuit (which is shown by the thick lines), they are shunted by non-inductive resistances, as shown. A more extended description of this arrangement, which was devised by H. M. Crane, will be given in the next chapter.

Stone's System.—This system was invented by J. S. Stone

in 1893, and is now much used, especially by the independent telephone companies in America. As shown in Fig. 237, it differs from the Hayes system in having a continuous line connection between the sub-stations when two are connected together through the exchange. The battery, C.B., is included

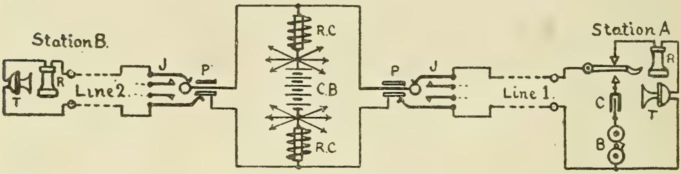


Fig. 237

in a shunt between the two conductors of the connecting cords, retardation coils, R.C., being interposed between the battery and the cords on each side, as shown. The original patent showed a pair of coils on one or both sides of the battery, as shown in Fig. 238, but a pair of coils joined up in such a manner is obviously equivalent to a single retardation coil of one

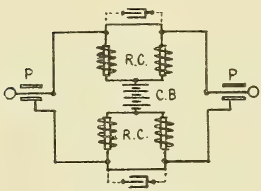


Fig. 238

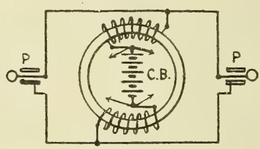


Fig. 239

half the resistance of one coil. In his later patents two such single coils are used, and both are wound on the same core, as shown in Fig. 239, this constituting what is now known as a "toroidal" coil or repeater.

The action which takes place when speaking is as follows :—The current from the battery, after passing through the re-

tardation coils, splits through the connected lines in proportion to their resistance. Supposing these to be equal, one half of the current will pass through each line and instrument; now, suppose the resistance of transmitter at station A to be reduced, this will immediately result in a fall of the potential at the points E and F, and this in its turn will cause a fall in current through the receiver at B. The opposite result would be produced at B were the transmitter at A raised in resistance. As variations in resistance are caused several hundred times in a second when speaking, and as the retardation or inductance coils offer very great obstruction to the resulting current waves, it results that practically a steady current is fed from the battery through the inductance coils, and the potential differences in the two lines act and react on each other, causing the current waves to pass through the lines, just as would happen if the battery were included directly in the line circuit. A disadvantage with this system is, however, that, if two lines of very unequal length and resistance are connected together, the current is unequally divided, most of it being fed through the short-distance line, and but little through the long-distance line. The use of doubled retardation coils connected by condensers, as shown in dotted lines in Fig. 238, to a large extent overcomes the difficulty mentioned above by keeping the two lines separate. The short-circuiting wires are, of course, not then used.

The same inventor also suggested the use of a dynamo for supplying the current in place of a battery, relying on the inductance coils to choke off the vibratory effects due to the commutator of the machine, which would otherwise give a humming noise in the receivers. By using a dynamo with a commutator having a large number of segments, so as to reduce the P.D. between each pair as much as possible, this has now proved practically successful.

The above described early C.B. systems are, it is believed, the most important, as they contain the germs of the systems which are now in extensive practical use.

The sub-station C.B. systems have been described in Chapter VII. To a large extent they are independent of the central station arrangements—that is to say, they will work in conjunction with any of the common methods of C.B. supply. The "Standard" sub-station arrangement is, however, generally associated with the Hayes C.B. system, and the other sub-station systems with the Stone C.B. system in America, but in this country the "Standard" sub-station arrangement is generally used even when the Stone system of current supply is used, as will be seen in connection with the Post Office exchanges.

CHAPTER XVII

COMMON BATTERY MULTIPLE SWITCH-BOARDS

Practical Details of C.B. Systems. (1) *Electrical Connections.*—Having given a short history of the more important C.B. systems, it now becomes necessary to describe how they are worked in actual practice.

Western Electric Co.'s System.—This system, which is the standard in this country, is used in the most important exchanges here and in America. It is a development of the Hayes system, with the Standard sub-station arrangement, and represents the latest C.B. practice.

Line Connections.—Fig. 240 is a sketch of the line connections somewhat simplified, showing one only of the multiple-jacks,

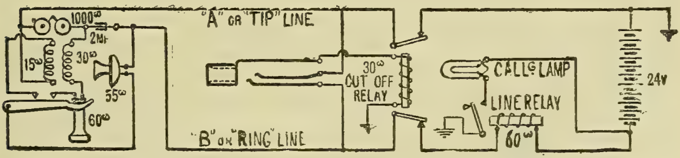


Fig. 240.—C.B. Line Connections simplified

which are all connected in parallel with the one shown. The positive pole of the 11-cell storage battery (24 volts) is shown connected to earth, the negative pole being connected through the line relay and a contact of the double cut-off relay, to the B wire of the line. The A wire is connected through the second contact of the cut-off relay, to the positive pole of the battery. As shown in the figure, there is a break in the line circuit at the sub-station instrument until the receiver is lifted, when the circuit is completed. The current then passes, and

operates the line relay, which in its turn closes a local circuit including the *calling lamp* and battery, when the lamp glows, and attracts attention.

NOTE.—In some of the older C.B. exchanges the line relay is connected in the "A" wire circuit and a 60-ohm resistance lamp is included in the "B" wire circuit. These were used to enable current to be fed through subscribers' lines for extension instrument working. The resistance lamps served by their glowing to detect excessive leakage on the "B" wires and a similar test was put on the "A" wires by connecting an earthed battery of two cells. As current for extension working is now supplied through special power leads and as it has been found that the continuous leakage tests can be dispensed with, the circuits have been modified to those shown in the figures.

Operators' Cord Circuit.—Fig. 241 shows the mai circuit of the cords and plugs. The latter, it will be seen, are 3-point, of the peculiar shape already described, to prevent the short-

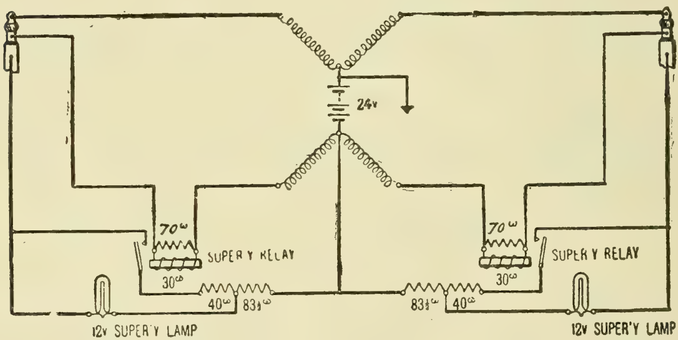


Fig. 241.—C.B. Cord Connections Simplified

circuiting of the jacks when they are inserted. The two tips of the plugs are connected together through two coils of the 4-coil repeater and the two rings of the plugs through the other two coils and the two supervisory relays.

The 24-volt battery (which is the same as shown in Fig. 240)

is connected between the two junction points of the repeating coils.

Each sleeve of the plugs is connected through a supervisory lamp and a $83\frac{1}{2}$-ohm resistance coil to the negative pole of the battery, and while current is circulating through the supervisory relays, shunts of 40 ohms are closed across the lamps to prevent their glowing.

Working.—The call having been made by taking up the receiver, the operator inserts one of the answering plugs into the answering-jack, which is fitted immediately over the calling lamp. This joins up the sleeve of the plug to the bush or socket of the jack. A current then passes from the negative pole of the battery through the supervisory lamp and shunt, through the coil of the double cut-off relay to earth, and back to the positive pole of the battery. The cut-off relay is operated, and breaks the connection of the line to the battery, line relay, calling lamp, etc. The current at the same time finds another path through a coil of the repeater, the line relay, the line, the sub-station instrument, the supervisory relay is operated closing the shunt circuit, and thus preventing the lamp from glowing. As the supervisory relays are directly in the speaking circuit, they are shunted by a non-inductive resistance so as not to interfere with the speaking efficiency.

The operator next connects her telephone to a pair of plugs and cords by pushing over the corresponding listening key, and ascertains the number required. She next tests the jack of the required line with the tip of the calling plug, and if no click is received (showing that the battery is not connected to the socket of the jack) she presses home the calling plug. This makes connections similar to those made on the answering plug side, except that until the called subscriber answers no current will pass to line, and the supervisory relay will not be operated, so that the supervisory lamp, not being shunted, will glow until the called subscriber takes off his receiver. The current will then pass, operate the supervisory relay and shunt the lamp, the extinguishing of which informs the operator that the subscriber has answered.

Double-Lamp Supervision.—When a connected subscriber has finished his conversation he hangs up his receiver. This causes a break in the battery circuit, so that the current ceases. The corresponding supervisory relay breaks the shunt across the corresponding lamp, and the increased current causes the lamp to glow. When both the supervisory lamps of a pair of connected lines glow, the operator removes the plugs, and restores the lines to their normal condition. She takes no notice of the glowing of a single lamp (unless it continues for a long time), as it is probably caused by one of the subscribers hanging up his receiver while he obtains some required information.

With this double-lamp supervisory system the operator can always have a definite knowledge of the various stages of a connection, so that there is seldom any necessity for her to plug into a circuit to find out whether the subscribers are speaking or have finished, as was the case with nearly all the older systems, and also with the single-lamp supervisory system. This greatly facilitates the operator's work, and enables her to attend to a larger number of lines.

The various resistances included in the circuits in order to reduce the currents to the necessary strengths for the proper working of the different pieces of apparatus are shown in the figures.

Complete Connections.—The full connections of the line circuit on the switch-board are shown in Fig. 242, in which the connections which are common to all the lines attended to by a single operator are drawn in broken lines or dashes, all those special to anyone line are drawn with alternate dots and dashes, whilst the connections spoken through when two lines are connected are drawn in thick continuous lines.

In addition to the apparatus shown in Fig. 240, there is shown a *pilot relay and lamp*, a subscribers' *service register*, and the connections on the distributing frame.

Pilot Relay.—This is a low resistance relay which is inserted in the line-relay local circuit so as to be common to all the calling lamps normally attended to by one operator. When-

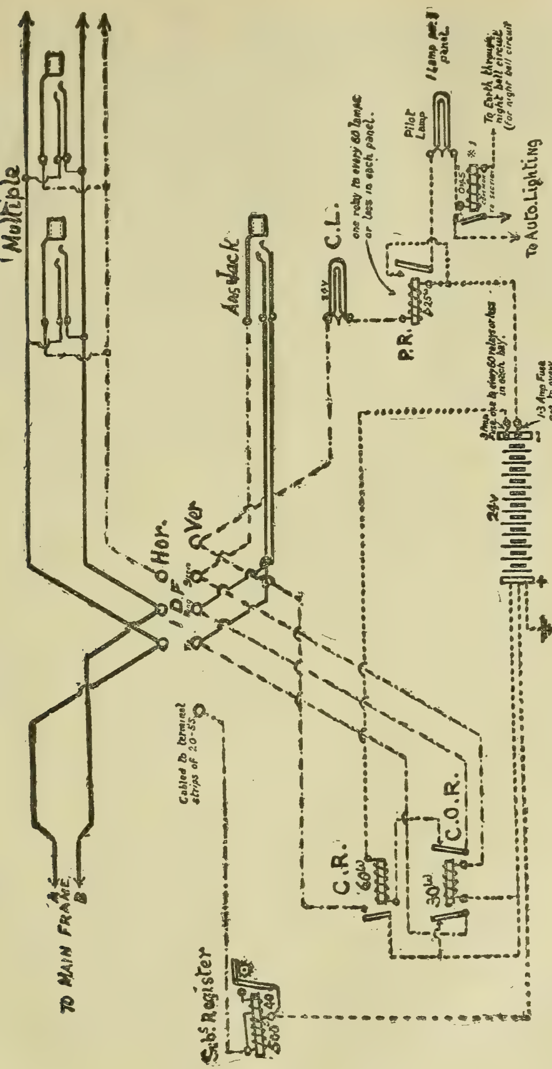


Fig. 242.—Complete C.B. Line Connections in Exchange

ever a call is made on any one of these lines the pilot relay is operated, and causes a specially large lamp, called the "pilot lamp," to glow. Being placed in a conspicuous position on the front of the switch-board, it attracts the operator's attention, and denotes the fact that a call is being made. The operator looks at the bank of lamps to find the particular one calling. As the pilot lamp can also be seen at some distance, it also enables the switch-room supervising operators to see that calls receive prompt attention.

Night-Bell Relay.—This is another low resistance relay in circuit with the pilot lamp. In its local circuit is connected either an ordinary trembler bell or a buzzer, according to which side the handle of a 2-way switch is turned. In the day-time the night-bell relay is short-circuited.

Service Register.—This is a counting instrument worked by an electro-magnet and ratchet wheel, and it is connected in parallel with the cut-off relays of each message-rate subscriber, so as to show, where necessary, the number of effective calls made. It requires for its operation a stronger current (about 42 milliamperes) to actuate it than is given when the cut-off relay is operated, and the extra strength is obtained by the depression of a *register key* (Fig. 243), one of which keys is connected to the third conductor of each answering cord. The key is pressed only when the operator is assured that the subscriber asked for has been obtained, but, in order to prevent any uncertainty in the registering, instructions are given to press the key only when the clearing signals are obtained from both the lines connected.

To make sure that the register works correctly *a register lamp* is included in the circuit with the register key. This lamp does not glow until the armature of the register magnet has been attracted, when a contact is made which cuts in a second low-resistance winding of the register magnet as a shunt to the 500-ohm coil, and so the current is strengthened. On seeing the lamp glow, the operator is assured that the register has been actuated.

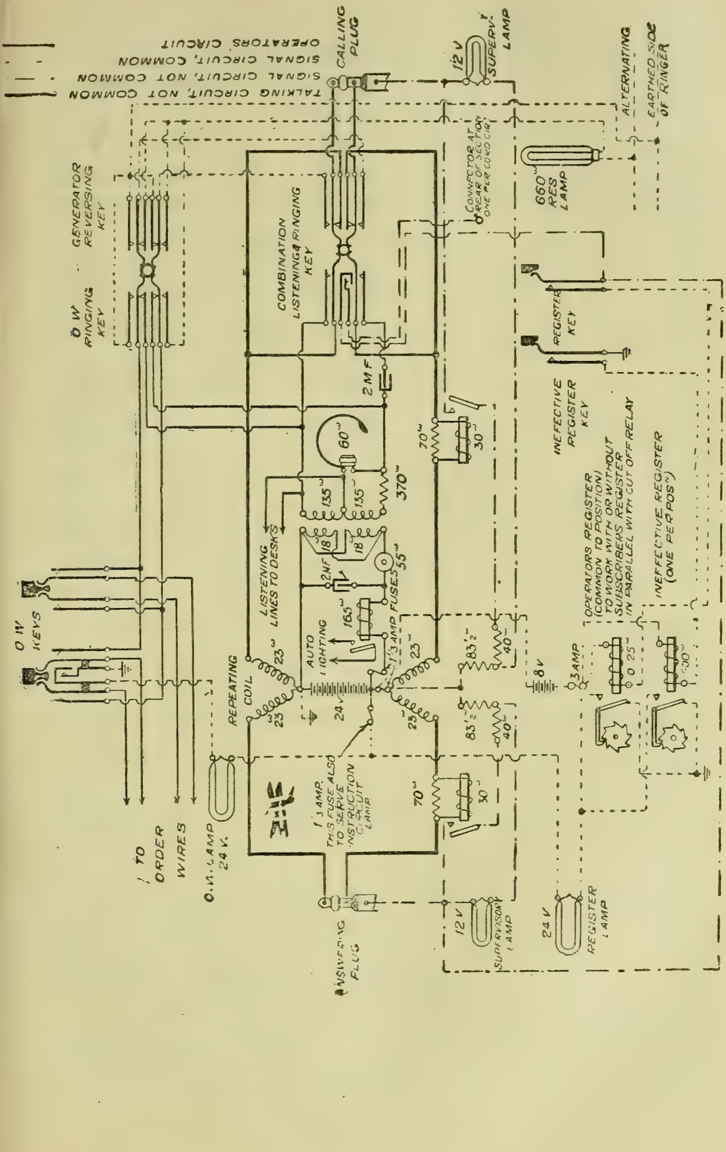


Fig. 243.—Operators' Cord Connections. C.B. Subscribers' Section

Operators' Cord Circuit.—Fig. 243 gives the full working connections of an operator's cord circuit on an ordinary subscribers' section of a C.B. switch-board. In addition to the parts shown in Fig. 241 there are the *register key and lamp* already described; another *operator's register*, worked by the same key, and intended to register all the calls attended to by an operator; also the *operator's telephone set*; combined *listening and ringing key*; *order or call wire keys*; *ringing keys* for the latter; and a *generator reversing* key.

Operators' Telephone Set.—The transmitter of this set is connected to the main battery through a retardation coil of 165 ohms, with a condenser connected as shown. The primary of the induction coil is wound in two sections, which are joined up in parallel. The secondary coil is also in two sections, but joined in series, one side of the receiver being connected to the junction point, and the other side to the opposite end of a resistance of 370 ohms connected to one end of the secondary coil. This 370 ohms is taken as the average resistance of a subscriber's speaking circuit; and when the operator is speaking on such an average line the receiver forms a sort of Wheatstone bridge to a balanced circuit; and what is termed the *side tone* is reduced to a minimum. By "side tone" is meant the reproduction in the receiver of the sound of the speaker's own voice when talking into the transmitter. With C.B. instruments this at times becomes disagreeably loud. A condenser is interposed in the secondary circuit to prevent the passage of current from the connecting cords.

Combined Ringing and Listening Key.—The connection of this key, the function of which has already been described in Chapter X, will readily be seen from the figure.

Order-Wire or Call-Wire Keys.—When connections are required to be made to subscribers whose lines are in other exchanges, the connections are made through *junction* lines which are run between the different exchanges. Instead of employing the usual signalling arrangements, however, the instructions for connecting are given verbally through separate *order* or *call* wires, several of which from the same or different

exchanges, are connected to the telephone of an operator who is continuously listening during the busy hours. This is found to be a much quicker and more satisfactory method than the ordinary method of signalling.

The distant ends of these order lines are connected to the springs (which are otherwise normally disconnected) of plunger keys, of which each operator may have as many as thirty, or more, connected to as many exchanges and to as many listening operators.

Order-Wire Ringing Keys.—During very slack hours the order-wire or "B" operators may cease listening, and connect their order wires to signalling apparatus, so that at such times a ringing key is needed to call them. One such key is fitted on each operator's position throughout the switch-board.

Generator Reversing Key.—This is another extra key for use with party lines on which two or more subscribers are connected to the same line. In such party lines some of the magneto bells are connected only to the "A" wire, these being for what are termed the "X" subscribers. Others are connected to the "B" wire of the loop for the "Y" subscribers, the other ends of the magneto bells being earthed. The reversing key is only needed when a "Y" subscriber has to be rung, as all the ordinary lines are rung through the "A" wire.

A 660-ohm resistance lamp is inserted in the generator circuit of each operator's position. This lamp glows when an

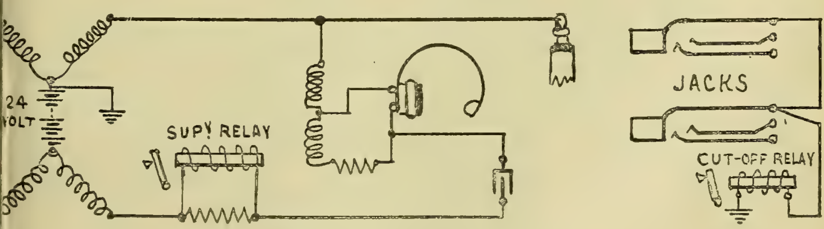


Fig. 244.—Testing Connections simplified

of the calling side of a pair of cords when about to make an engaged test, and also shows two jacks of an unconnected line with the cut-off relay, while Fig. 245 shows a similar pair of jacks, one being connected to the third conductor of a plug and cord. In the latter case the engaged click would be obtained when the tip of the plug (Fig. 244) touched the socket of the unoccupied jack. This click would not be caused by a direct current passing from the battery through the receiver, but by a partial discharge current passing from the condenser, owing to the difference of potential between the two coatings of the condenser being reduced when a current passes through the tip conductor, the P.D. having been previously equal to the full voltage of the battery.

Speaking Connections.—Fig. 246 shows the simplified speaking circuit when two sub-stations are connected through a switch-board. It will be readily understood without further description.

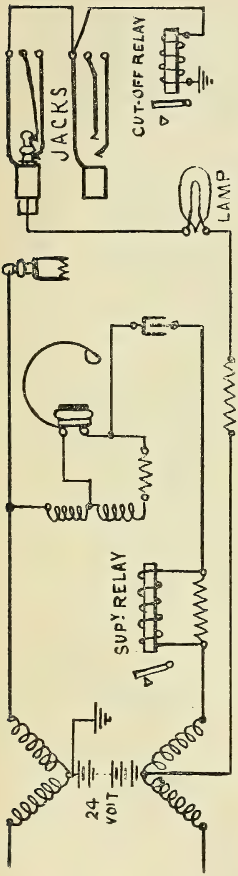


Fig. 245.—Operators' Connections for C.B. Switch-board, simplified.

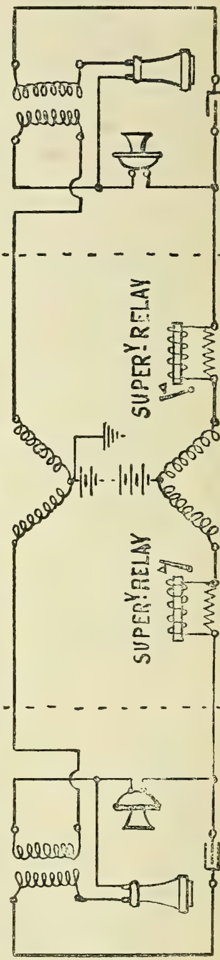
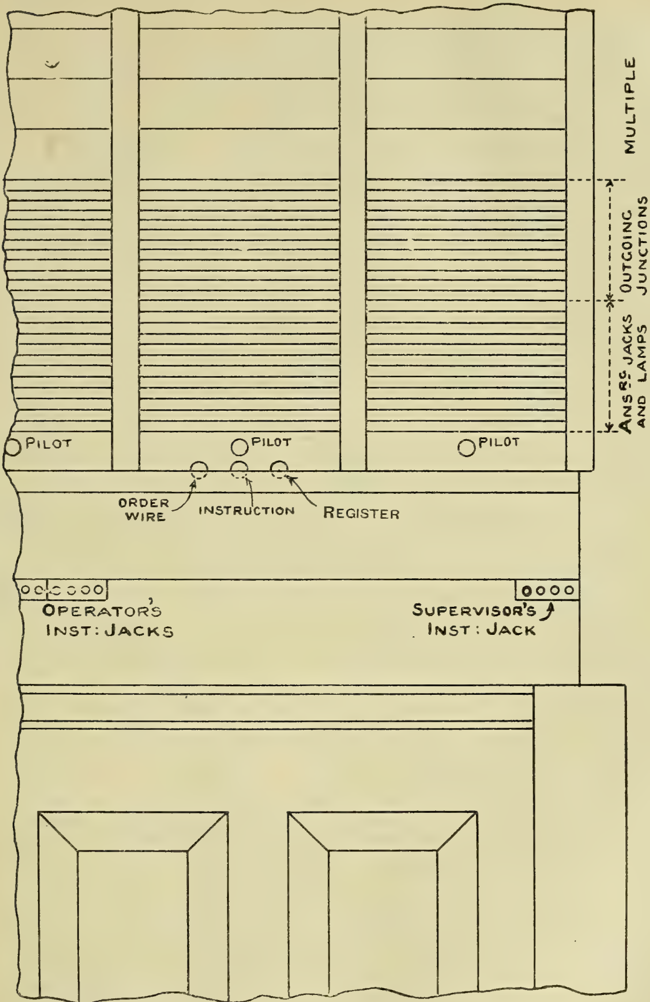


Fig. 246.—Subscribers connected for Speaking. Simplified connections.

Barnsbury Switch-Board.—In order to facilitate the description of the practical construction of a modern C.B. switch-



ELEVATION

Fig. 247.—Scale ⅐

board, it is thought advisable to describe briefly the leading features of the "Barnsbury" or "North London" Exchange, which is one of the more recent of the many National Telephone Co.'s London exchanges. Fig. 247 is a detailed sketch of part of the front of one of the sections of the board, showing the relative positions of the various jacks, calling lamps, etc. Fig. 248 is a section of the most important part, showing the operators' key-board, and Fig. 249 is a plan of one operator's position on the section, showing the operator's keys, supervisory lamps, etc.

Key-Board.—Each operator is furnished with 17 pairs of 3-way cords and plugs, and with each pair of these is associated a combined listening and ringing key, two supervisory lamps, and a register key. These are all set in lines, so that the number plate applies to all.

On the right-hand side of this set of 17 keys is the order-wire ringing key, the function of which has already been described, and in front of this is the party-line reversing key, of button form, while at the back is another button key, called the *ineffective register key*, for registering ineffective calls made by the operator.

On the left-hand side are fitted 50 order-wire keys of the button form, in 5 rows of 10 each, and in front of the R. and L. keys 26 more of these order-wire keys are fitted. These keys are lettered with the initials or code letters of the various London exchanges, with which they are connected by call lines, instead of being plain as shown in Fig 249.

It will be noticed from Fig. 248 that the key-board slants downward towards the back; this gives a comfortable arrangement for the operator, and gives a greater area on the upright portion for the multiple and other jacks.

In order to provide for the long connecting cords required for such large exchanges, the sections are fitted with a special pulley arrangement, shown in Fig. 248. From the plug the cord passes through the hole in the plug shelf, and down under one of two pulleys fitted in a double pulley weight, of the shape shown in side and end view at the bottom of Fig. 248. The

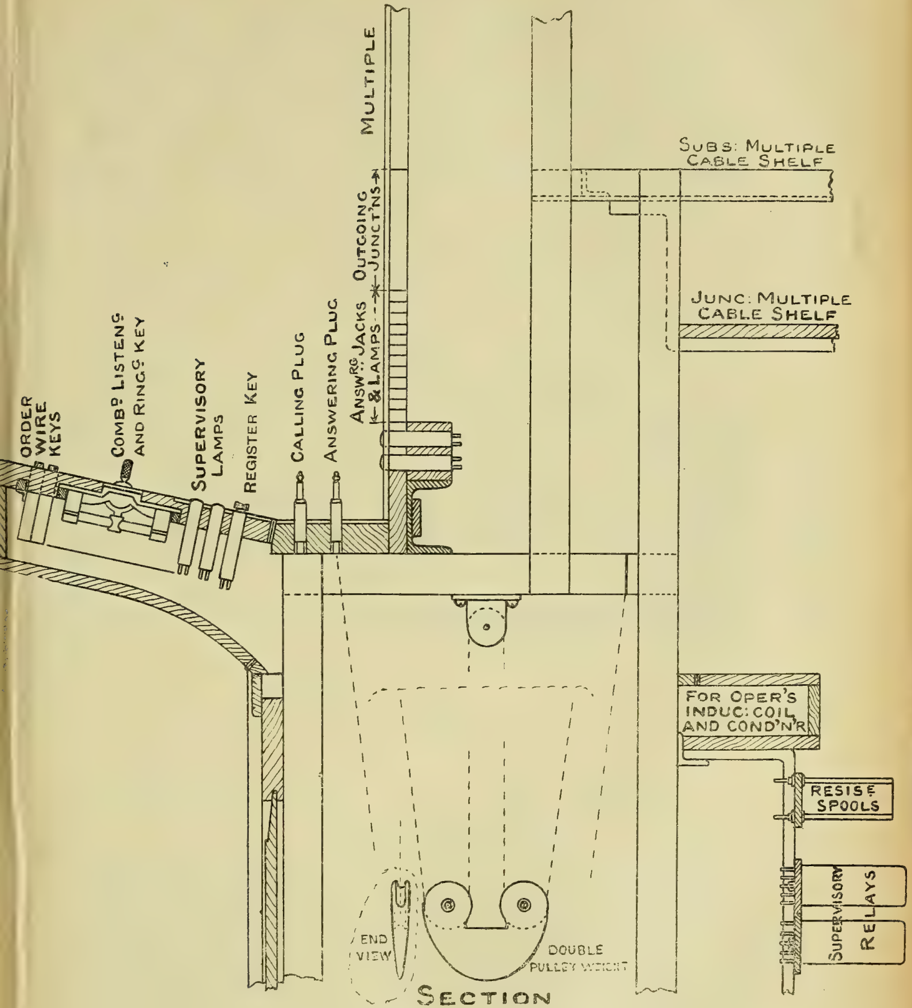


Fig. 248.—Scale ¼

cord then rises and passes over a pulley fixed under the frame, then down again under the second pulley of the pulley weight, and finally it passes upward through a hole in the cord-fastener shelf to the fasteners. This arrangement enables the cords to be pulled out about 8 feet, so as to stretch to every part of the "jack-field" of a section. The pulley weights are made wedge-shaped at the bottom, so that they

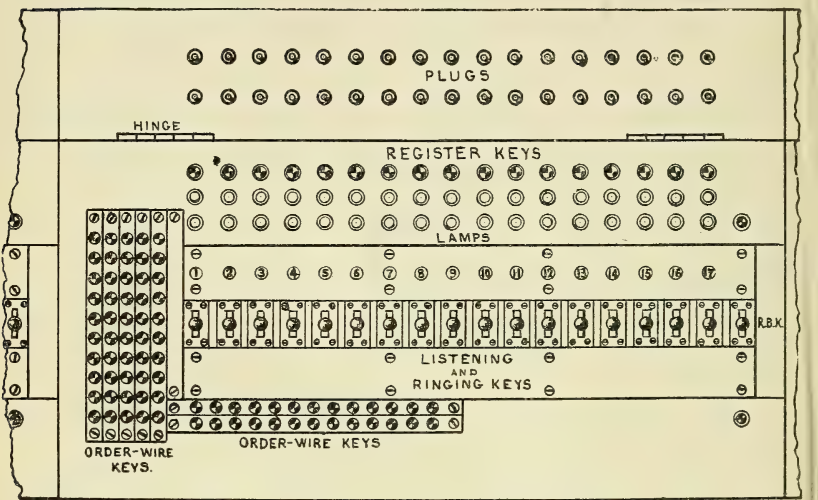


Fig. 249.—Scale $\frac{1}{6}$

may more readily make their way between the others, and thus prevent crossing and entanglement.

Another method of providing for a long cord is to build the switch-board on a false floor, raised about 1 foot or more above the ordinary floor, an opening being left for the pulley weights to pass through. This construction adds 2 feet, or double the height of the false floor, to the practical length of the cords.

Plug Shelf.—To prevent damage and noise caused by the falling of the plugs on the plug shelf, the face of the latter is covered with sole leather about $\frac{1}{4}$ inch thick. The opal

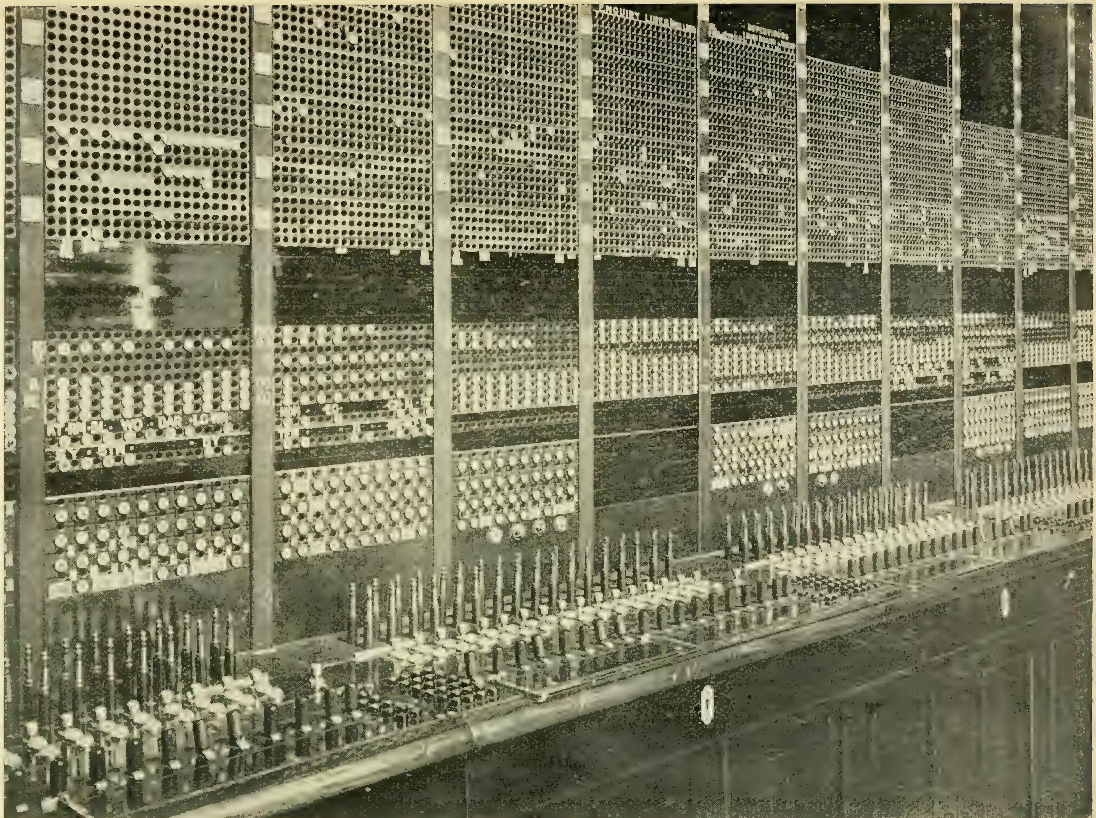


Fig. 249*a*.—FRONT VIEW OF COMMON BATTERY MULTIPLE SWITCHBOARD

caps of the supervisory lamps are also protected from damage by perforated metal caps.

Operators' Jacks.—On the under side of the key-board two instrument jacks are fitted to each operator's position—one to connect her own telephone set, and the other so that a second set may be connected for a learner or a supervisor.

All the switches, etc., fitted under the key-board are boxed in, so as to render them dust-proof, and each key-board is hinged at the back, so that it may be raised for inspection of the fittings, etc.

Jack-Field.—The front of the switch-board, where the jacks, calling lamps, etc., are fitted, is called the "jack-field." There are eight panels in each section of the Barnsbury board, and at the bottom of each panel is fitted the pilot lamp, which is lit each time any calling lamp in that panel glows. The "calling" lamps and "answering" jacks are fitted at the lower part in alternate rows of 10, the jacks being fitted above the corresponding lamps. Above these again are fitted "outgoing-junction" jacks in rows of 10, through which jacks connections are made for calls to other exchanges, no calls being received from other exchanges, so that no signalling apparatus is fitted at the "outgoing" end.

Fig. 250 gives a photographic view of the front of a complete subscriber's section of the board, with one of the keyboards lifted to show the wiring of the switches, etc. See also Fig. 249*a*, which gives a view of a subscriber's section of the Holborn (London) C.B. switch-board. This board is shown fitted for 4600 subscribers' lines. The positions of the keys, lamps, etc., are clearly shown.

The subscribers' "multiple" jacks are fitted above the outgoing-junction jacks in strips of 20, 5 strips being grouped together so as to give sets of 100, which are separated from other sets by thin strips of white wood. All such sets of 100 are numbered from 0 to 99, and each set is numbered by a white number painted on a black "number-style strip" fitted on the left-hand side of each set. The first of such sets (which usually commences on the left of each section on the

lowest multiple row) is numbered 0, for numbers ranging from 0 to 99. The next set to the right is numbered 1, and is for lines numbered from 100 to 199. The third set is numbered 2, for numbers from 200 to 299, and so on to the ninth set, which is numbered 8, for 800 to 899. The tenth set is fitted

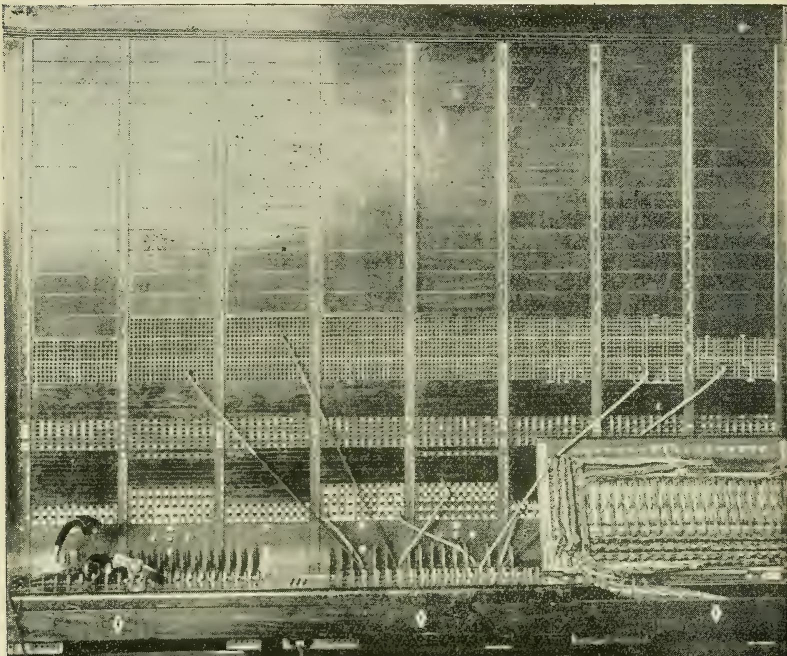


Fig. 250.—Subscribers' Section

over the 0 set, and numbered 9, thus commencing another row of hundreds, numbered from 9 to 17, the latter being fitted over the ninth set, numbered 8, and so on, building upward until the full number of subscribers has been provided for.

It might at first sight have been thought more convenient to fit the subscribers' multiple-jacks in a lower position in

the panels, but as some 80 per cent. of the calls in London are for subscribers in other central offices, it is clearly of more importance in London to have the junction-line jacks in the more convenient position. For the same reason, it has been found advantageous to multiple the outgoing junction-line jacks more frequently than the subscribers' jacks, so that in the exchange in question they are multipled every 6 panels instead of every 9. This enables junction lines to be very easily and rapidly reached for testing and connecting.

Both these methods of multipling are radical departures from the universal practice of a few years ago. It was usual then to multiple both subscribers and junction lines on the number of panels which each section contained, so that each section could be treated as a complete unit in itself. An 8-panel section would be multipled in 8 panels, the numbers of the 100 sets having the same relative position on each section. It has now, however, become the practice to treat the multipling as quite independent of the section, which latter is determined by the space in which three operators can conveniently work.

Instruction Lamps.—In the centre of each operator's position there are provided three large lamps, seen in Figs. 247 and 250. The right-hand one is the register lamp, already mentioned; the centre one, coloured green, is the "instruction" lamp, and is used to call the operator's attention to an instruction to be given by one of the supervisory officers to one or more of the operators. All the green lamps on the switch-board glow simultaneously, and each of the operators thereupon presses a special order-wire key, and listens to the instruction. The left-hand lamp is a red one, and is called the "special order-wire" lamp. It is intended to call attention to the fact that a special charge is to be made for the call. It glows only when an order-wire key is pressed which connects to a central office situated out of the ordinary territory, and for which an extra fee is exacted.

Fig. 251 is a detailed plan of the "Barnsbury" switch-room, showing the positions of the various subscriber and junction sections, operators' positions, etc. The operators' positions

are all numbered, and it will be noticed that all the "A" positions have even numbers and all the "B" positions odd numbers. The positions are also shown of the monitor's, the

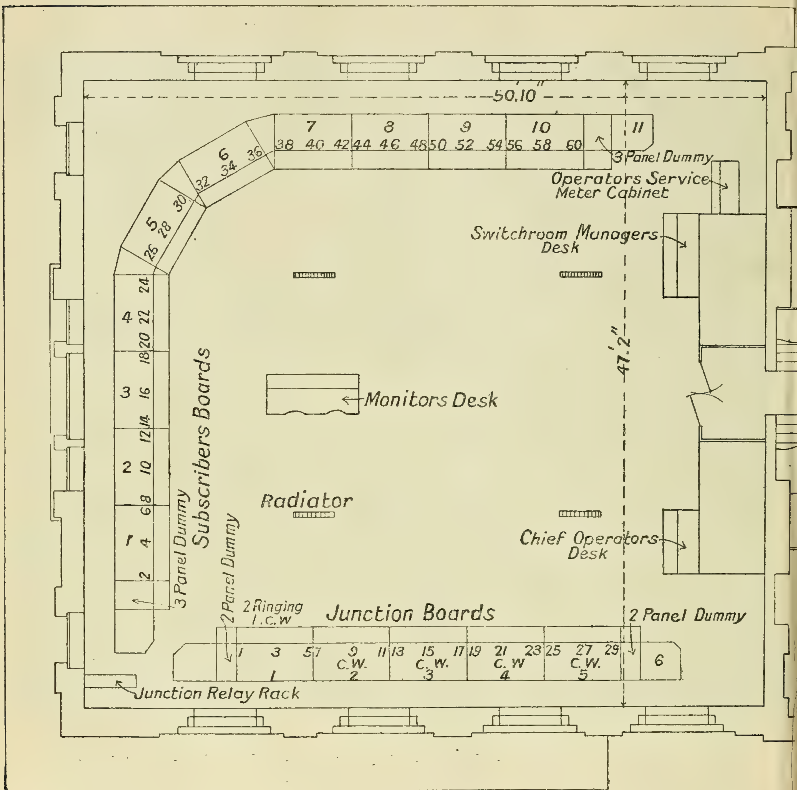


Fig. 251

chief operator's, and the switch-room manager's desks. The monitors have the means of plugging into circuit with any of the operators' instruments, so that they can check any slackness or unnecessary talking on the part of the operators.

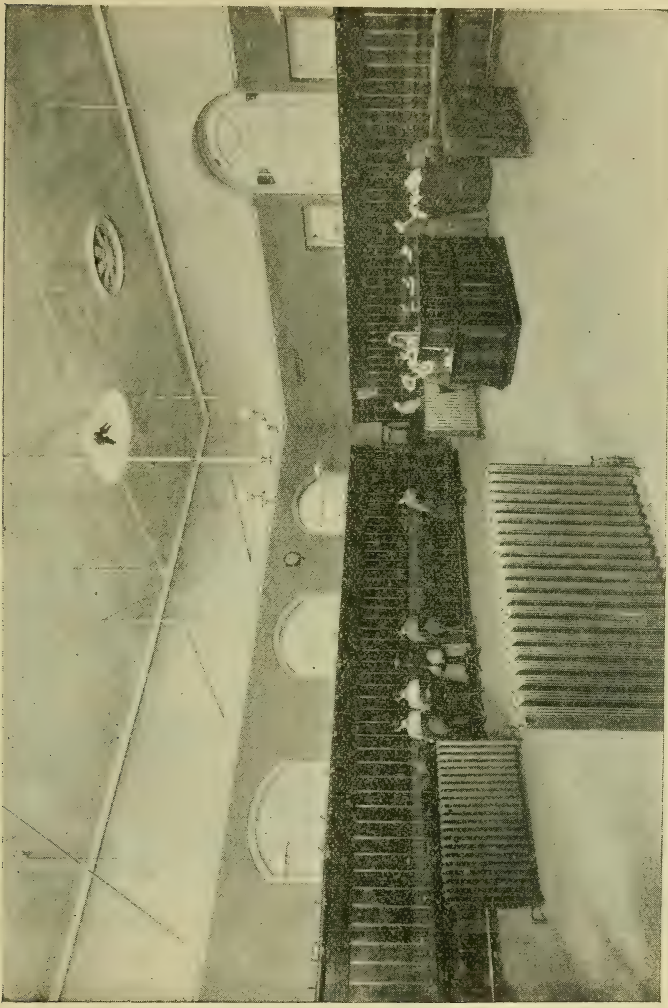


Fig. 252.—Switch-room

A general view of the switch-room is given in Fig. 252, as

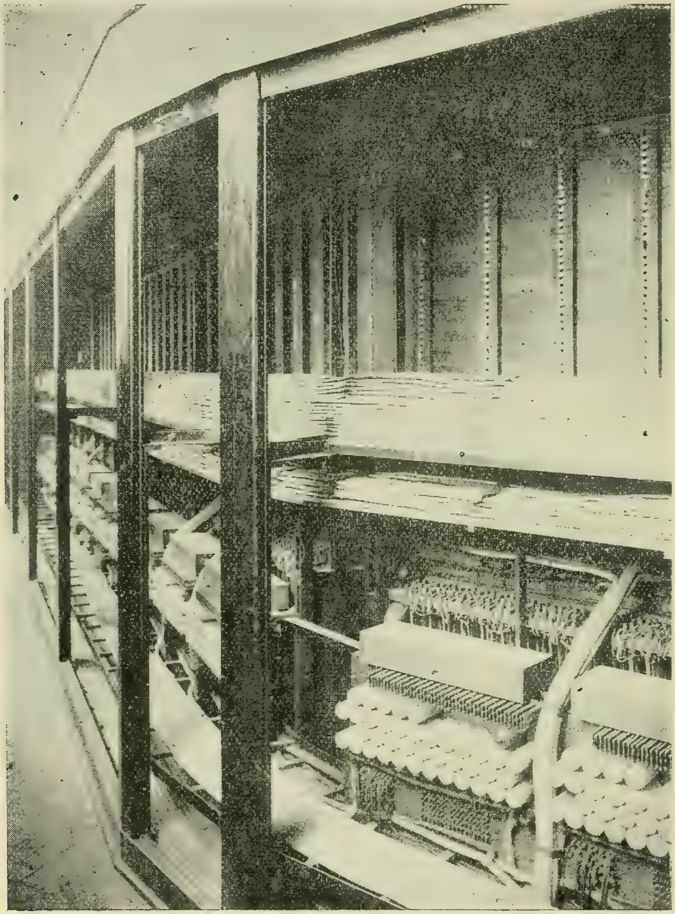


Fig. 253.--Back of Switch-board

seen from near the switch-room manager's desk. Only very few of the operators are in attendance.

Fig. 253 is a view of the back of the subscribers' sections of the switch-board. The cables for the answering jacks are seen at the bottom, and above are those from the repeater coils. The white cylinders above these are the supervisory relays in cases, and above these are the resistance spools, protected by mica plates. The boxes above these contain the operators' induction coils, etc., and above these are the cord-fastener shelves, then the cables for the calling-lamps and jacks. Still higher are the outgoing junction cables, and then the subscribers' cables. The back is closed in by roller shutters, such as is fitted to shop fronts.

Resistance Spools.—The resistances used as shunts, etc., in connection with C.B. working, are made up of German silver wire, of 4 or 5 mils diameter, which will safely carry a current of 0·2 amperes.

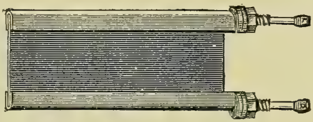


Fig. 253*a*.—Scale $\frac{1}{3}$

The length of bare wire is wound on an oblong strip of micanite so that the turns do not touch each other, and this strip is wrapped in thin micanite sheet. The two ends of the wire are brought out and soldered to two brass clip strips which bind over the edges of the micanite and have soldering tabs, screws, and insulating washers attached, as shown in Fig. 253*a*, so that they may be screwed on iron base plates, which are fitted on the lower part of the switch-boards.

Service Markings.—Owing to the large variety of services to which subscribers may be entitled, it is necessary to provide something which shall inform the operators at a glance which facilities shall or shall not be allowed to each of her subscribers, and also to direct her as to when a record of the call is to be made, or a fee demanded. This object is attained on non-lamp signalling switch-boards by special markings or colourings on the number pegs or plates which are provided over or by the side of each of the answering-jacks.

Lamp Cap Markings.—The opal caps of the calling lamps in lamp-signalling exchanges lend themselves very con-

veniently for these service markings, as the light behind throws up the markings very distinctly, and no extra space is required for them.

The principal markings adopted by the National Telephone Co. are shown in Fig. 254.

As seen in Nos. 4 and 6, etc., of Fig. 254, two of the single markings may be combined on the same cap.

When the markings appear on a *white* ground no record or

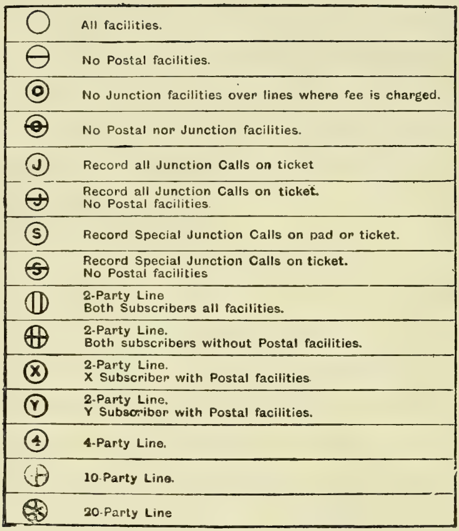


Fig. 254

ticket is needed, but if they appear on a *green* ground a record is to be made on a ticket, and if on a *red* ground a fee is to be demanded for the call.

Markings on Multiple-Jacks.—When a subscriber has two or more separate lines to the exchange an endeavour is made, as far as possible, to give consecutive numbers on the switchboard; and in order to inform the operator of the fact a line is painted under the jacks in the multiple section, so that she

may connect to another line if one is engaged. The markings greatly assist the operators in their work.

Automatic Night Lighting.—In order to economise the electric-light current at night an arrangement known as the Belfast system is used in the more important exchanges. An extra relay, A (Fig. 255), is included in the pilot lamp and night-bell relay, N.B.R., circuit. When a subscriber lifts his receiver at night, the relay A is actuated, and closes a circuit in which is a powerful electro-magnet, E.M., when the double-

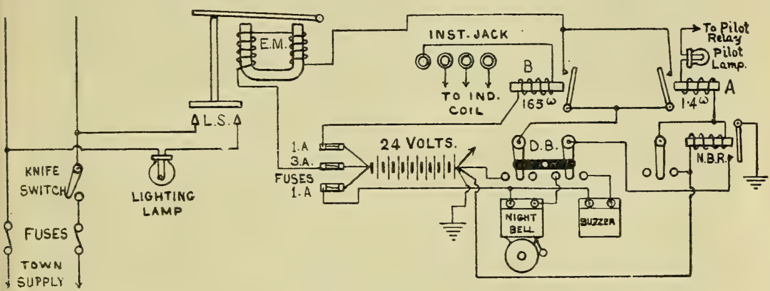


Fig. 255

bar switch, D.B., is to the left. The armature of E.M. when attracted closes the lighting switch, L.S., which lights a lamp over the section on which the call is made.

When the night operator inserts his instrument plug into the instrument-jack of the section, the relay B is brought into play, so as to take the place of relay A when the latter is cut out by the insertion of the answering plug into the jack of the calling line.

In a magneto exchange the relay A is included in the night-bell circuit.

CHAPTER XVIII

JUNCTION-LINE WORKING

Most large towns have several exchanges, as it is found more economical to have central offices in the various localities than to run all the wires to one central office, although the latter would constitute the ideal arrangement from the operating point of view. It would, however, be subject to the disadvantage that in the case of a fire at the one exchange the whole of the telephonic system of the town would be deranged. Again, the lengths of the subscribers' lines would be necessarily much greater. A multiple switchboard having jacks spaced at half-inch centres, vertically, reaches its practical limit when the number of lines attain to about 9600, or, with the newer $\frac{3}{8}$-inch jacks, when about 15,000 is reached, so that if the number of lines in a town exceeds these figures it is a practical necessity to have more than one exchange, but see Chapter XXIX. for special systems of working.

Different exchanges in one exchange area are joined together by "junction" lines, by means of which subscribers' lines centred in one exchange are connected to those in another exchange. The efficient working of these junction lines is of the greatest importance in giving a good service, especially in very large towns, such as London, where nearly 80 per cent. of the connections are made through junction lines. Much thought has been devoted to the devising of a junction system which will entail the minimum of time and trouble to the operators in connecting and disconnecting.

The proportion of junction lines to subscribers' lines varies with the different districts, according to the number of ex-

changes. In London, where there are a large number of exchanges (about sixty), the proportion is about 33·3 per cent.

Order Wires.—The instructions for connections on junction lines between important exchanges are always given by means of " order " wires, as described in the previous chapter. When such order wires are not used, the connecting lines are called " ringing " junctions.

Incoming and Outgoing Junctions.—The junction lines between any two important exchanges, say E and F, are, as before stated, divided into two sets—one set used for calls from E to F, and the other set for calls from F to E. The first set will be " outgoing " at the E exchange and " incoming " at F, and the other set will be outgoing at F and incoming at E.

The proportion between the two kinds of junctions at any one exchange will vary according to the numbers of calls to and from that exchange.

Outgoing junctions are multipled on the subscribers' sections like ordinary lines, so that any operator can use any one line, and they are connected and attended to in a somewhat similar manner by the A operators. Incoming junctions are not multipled, but are collected on special " junction sections " of the switch-board, and are attended to by special or B operators. The apparatus connected to incoming junctions is generally complicated, while that of outgoing junctions is simple, consisting generally only of a 3-point jack and a resistance coil.

Ringing and Order-Wire Junctions.—When the traffic between two exchanges is small, and not sufficient to warrant continual listening on an order wire, the junctions are worked by signalling, and are then termed " ringing " junctions.

In some cases an order wire may be used for calls from a branch exchange to a main exchange, and ringing junctions the reverse way.

Order-wire working is much the quicker method, as instantaneous connection can be made to the listening operator, and quicker connection to the junction, as the latter operator

can see at a glance what junction wire to use. There is, therefore, no need to make an engaged test, as is the case with multipled ringing junctions.

Junction Control.—The usual plan of working junction lines is for the operator who receives the original call, and connects at the outgoing end of the junction line, to have complete control of the whole connection. The clearing signal from the called subscriber is received by her, and she gives the clearing signal automatically to the incoming junction operator by the operation of withdrawing the connecting plug from the jack.

Junction Lines between C.B. Exchanges.—Confining our attention to the thick-line portion of the lower part of Fig. 256 which shows the part of the circuit which is spoken over, and starting from the left-hand side, we have first the connecting-jack at the outgoing exchange, then the actual line wires, leading to the 4-coil translator at the incoming exchange. The two windings on the left are separated altogether from those on the right, but are joined to each other by a condenser, which has as a shunt a 12,000-ohm coil of a double-wound relay, which coil, however, is itself shunted by a 27-ohm winding when the supervisory relay at S is energised. The contact of this latter relay acts in relation to the plug connections at the outgoing end as the switch-hook of an ordinary subscriber's instrument, as, when the contact is broken, the clearing lamp is operated at the outgoing exchange. The main battery is connected between the right-hand coils of the translator, and the line connections pass through the two ringing keys RK_1 and RK_2, the latter being fitted with ringing control and RK_1 being without machine control so that it may be used for code ringing on party lines. The A or "tip" wire connection passes through the top contacts of relays J and O (when these are energised) to the tip of the 3-way plug on which the junction line ends. Nearly all kinds of incoming junction lines end in this manner on a single cord and plug.

The relay J is used in place of the 40-ohm shunt to the 12-volt clearing lamp and serves to prevent the called-for subscriber being rung unless the junction line connection is properly completed to the calling subscriber, as the connecting cord contacts are only completed when this relay is actuated. The 360-ohm shunt also serves to prevent the 12,000-ohm relay sticking at the contacts, which it was apt to do owing to the capacity or inductance of the local circuit.

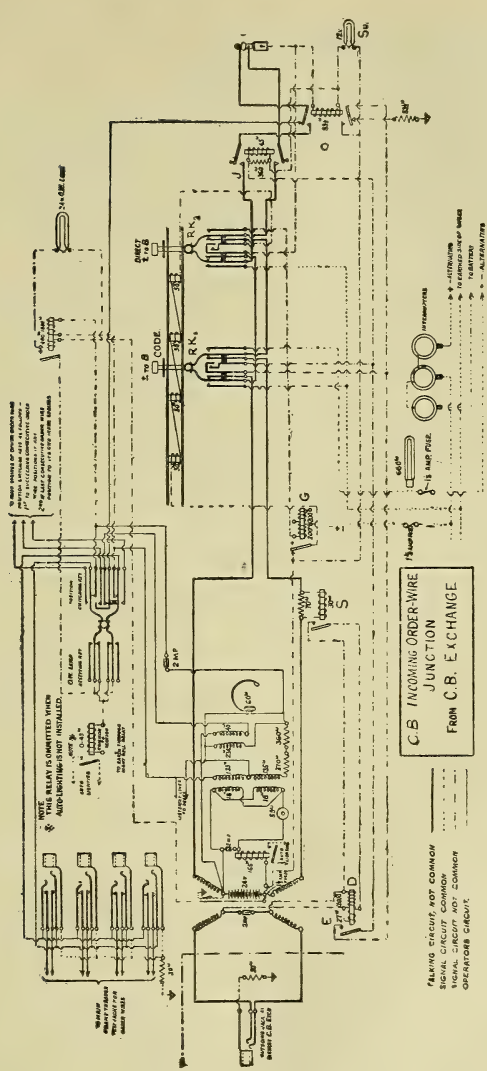


Fig. 256.—C.B. Incoming Order-Wire Junction from C.B. Exchange

The upper part of the diagram shows the connections of four order wires to the operator's telephone, the break-jacks to which they are connected being for use only when any of the order wires become faulty, the insertion of a plug cutting off the faulty wire. A switch is also inserted, so that the order wires may be switched on to the next operator, and a lamp for use at slack times, when the operator is not continuously listening. Not more than four order wires should be allotted to one operator.

Operating.—The "A" operator at the outgoing end, on receiving a call from one of her subscribers for a line connected to another exchange, asks for the required number over an order wire connecting to that exchange, and is informed by the incoming or "B" operator which junction line is to be used for the connection, as the latter can see which lines are disengaged. When the "A" operator connects the calling subscriber with the junction line her calling supervisory lamp will light, as the circuit through the lamp from the battery is completed through the 30-ohm resistance connected to the bush of the outgoing-jack, while the resistance of the 12,000-ohm relay prevents the supervisory relay from being actuated. Should the "A" operator make connection before the "B" operator, the clearing lamp at the incoming end will also light, as the 12,000-ohm relay will operate and complete a circuit from battery through the lamp, the coils of relay J, contact of 12,000-ohm relay, the armature, and back contact of relay O, through the $83\frac{1}{2}$-ohm resistance coil to earth. If the "A" operator should by mistake plug into a wrong junction line, the lamp of that line at the "B" end would light up and thus indicate the mistake to the "B" operator.

When the "B" operator inserts the junction-line plug into the required subscriber's jack, the relay O is actuated, and the lamp circuit is completed through the same relay and the cut-off relay of the called subscriber; but as a shunt of 40 ohms (relay J and shunt) is put across the lamp through the contact of the 12,000-ohm relay, the lamp does not glow.

The usual practice is for the "B" operator to ring up the subscriber, and, to facilitate rapid working, automatic or "machine" keys are provided, which on being depressed apply an interrupted alternating current to the line until the subscriber replies. When the condenser at the subscriber's end is cut out of the circuit by the removal of the receiver from the rest, the relay G which controls the energising current of the electro-magnet clutch is actuated, and the ringing current is disconnected At the same time the supervisory relay at the incoming end is also actuated, and the 12,000-ohm relay is shunted by its 27-ohm winding, thus allowing sufficient current to flow through the calling supervisory at the outgoing end to actuate it and shunt out the supervisory lamp. The "A" operator is thus advised when the called subscriber replies, without being obliged to remain in circuit, and as each of her supervisory lamps responds to the movements of the respective subscribers' rests she is able to supervise the connection just as if it were a local call, and to disconnect at the termination of the conversation.

When the "A" operator withdraws the calling plug from the junction-line jack the armature of the 12,000-ohm relay at the incoming end falls back, breaking the shunt across the clearing lamp, which lights, and gives the clearing signal to the "B" operator to disconnect. When the "B" operator withdraws the junction-line plug, the armature of relay O returns to the normal position, and the clearing lamp goes out.

Fig. 257 illustrates a complete connection when in the ringing condition. At the outgoing end the supervisory lamp in the answering plug circuit is shunted out by relay A, as the subscriber has his telephone off the rest. The called subscriber at the "B" exchange has his telephone on the rest, and as the operator has depressed the machine ringing key N there is a circuit from the earthed generator, through inter rupters and front coil of relay G, through outer contact of key N and lower contact of relay J to ring of plug, and thence round instrument to tip of plug, contacts of relays O and J, key N. and

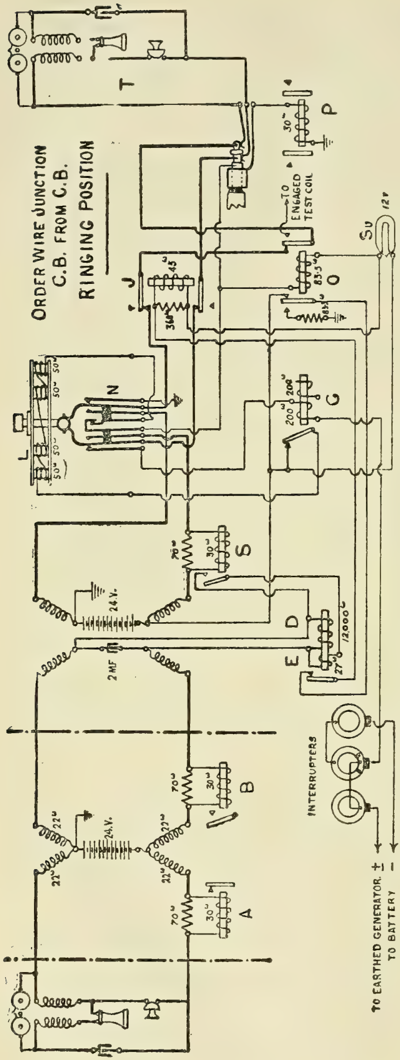


Fig. 257.—Order Wire Junction C.B. from C.B.—Ringing Position

earth. The bell is therefore, rung; but there is not sufficient current to actuate relay G, and the machine key is held down by electro-magnet coils L, which are energised by current from battery through contact of relay G, key N, sleeve of plug and bush of jack to cut-off relay P and earth. When the telephone at T is removed from the rest, the increased ringing current actuates relay G. This opens circuit through L, thus releasing plunger of key N, which flies back to the normal position.

During the time the subscriber is being rung there is no circuit through relay S and therefore the 12,000-ohm coil of relay D is not shunted by low-resistance coil E, and consequently relay B is also open and the calling supervisory lamp at the A end of circuit is alight.

The interrupter connects up the ringer for three seconds and then earth for three seconds. If the subscriber T removes his telephone from the rest during an interval in the ringing, the relay is still actuated by the 24-volt battery through subscriber's instrument to the earth on key N.

Fig. 258 illustrates the same circuit in the through speaking position. Supervisory relay S is actuated, thus connecting low-resistance coil E in parallel with 12,000-ohm coil D, and thereby actuating relay B at the "A" exchange. Relay O is actuated through cut-off relay P, the right armature of O has disconnected the engaged-test coil and connected the tip of plug through relay J. The left armature disconnects 83·5-ohm spool and earth from contact of relay D, and shunts lamp S_u with coils of

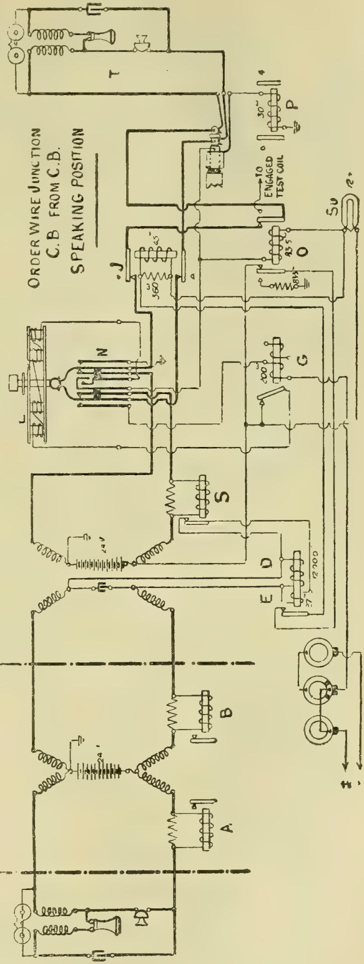


Fig. 258.—Order Wire Junction C.B. from C.B.—Speaking Position

relay J whilst the armature and contact of D are closed. When the subscriber T hangs up, relay S opens, and consequently relay B, as explained previously. When the operator has received both signals, A and B, she withdraws plugs, and thus releases armature of relay D; lamp S_u therefore glows, and "B" operator clears.

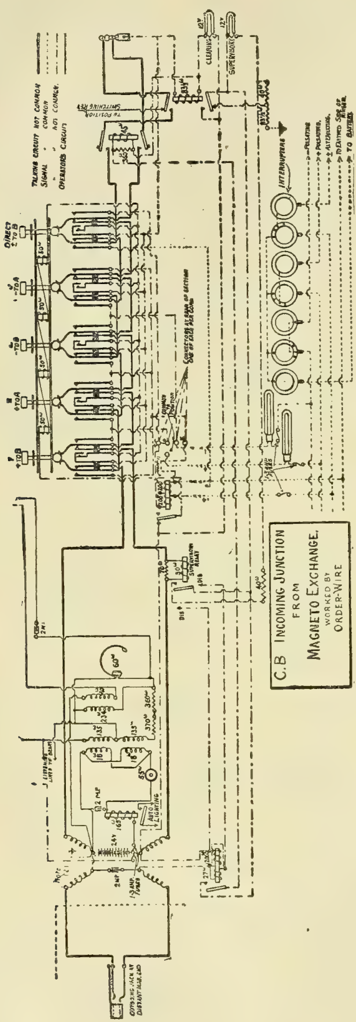


Fig. 259

Although the above appears very complicated, and takes considerable space to describe, in actual practice the system is very simple and rapid, and leads to great economy in junction lines and operators' time.

Junctions between C.B. and Magneto Exchanges. — If the incoming end of the junction line is at the C.B. exchange, the connections and working are somewhat similar to those of a line between two C.B. exchanges. Two clearing lamps are, however, provided at the incoming end, as

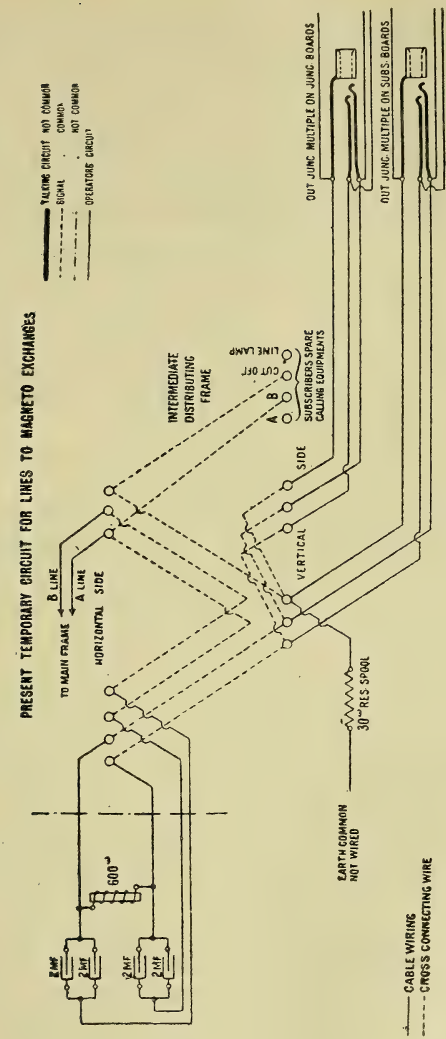

PRESENT TEMPORARY CIRCUIT FOR LINES TO MAGNETO EXCHANGES
TALKING CIRCUIT NOT COMMON
SIGNAL " COMMON
" " NOT COMMON
OPERATORS CIRCUIT
TO MAIN FRAME
B LINE
A LINE
HORIZONTAL SIDE
INTERMEDIATE DISTRIBUTING FRAME
LINE LAMP
CUT OFF
A
B
SUBSCRIBERS SPARE CALLING EQUIPMENTS
VERTICAL
SIDE
OUT JUNC MULTIPLE ON JUNC BOARDS
OUT JUNC. MULTIPLE ON SUBS. BOARDS
600
2MF
2MF
2MF
2MF
30 RES SPOOL
EARTH COMMON NOT WIRED
CABLE WIRING
CROSS CONNECTING WIRE

Fig. 260

shown in Fig. 259, the lower one being controlled by the called subscriber, and the upper one by the "A" operator, through the 12,000-ohm coil of the relay D, the 27-ohm winding not being needed. Fig. 259 shows in addition the connections of a complete 5-key party-line equipment, for description of which see Chap. XX. The connections apart from this Key might be considerably simplified but that the apparatus is so arranged that it may be converted into a complete C.B. system at any time. There is no earth connection on the bush of the jack at the outgoing end. The current from the 24-volt battery passes through the left-hand coils of the translator and the 12,000-ohm relay to the magneto exchange when a plug is connected into the jack; but when the plug is taken out the connection is broken, the lamp shunt contact at this relay is opened, and the upper lamp lights.

The connections to the order wire are not shown, but are exactly similar to those of Fig. 256.

If the incoming end of the junction wire is at the magneto-exchange end, the connections at the C.B. exchange are as shown in Fig. 260. Condensers are inserted in the junction line to prevent flow of current, and a 600-ohm retardation coil is bridged across the line at the outgoing end to put out the calling supervisory lamp directly the A operator makes connection with the junction wire. The A operator has to listen to ascertain when the called subscriber replies, and again when the calling subscriber hangs up his receiver and gives the clearing signal to the B operator.

The cross connections for subscribers' spare calling equipments are made in order to put earthed battery on the A line when the operator withdraws her plug, thus giving the clearing signal to the B operator. By this means temporary working arrangements are made without the introduction of apparatus which will be useless when the conversion of the incoming end to central-battery working is made. Fig. 261 shows how the connections are modified when the conversion is made.

Junctions between Magneto Exchanges.—Fig. 262 gives the

full connections of an order-wire junction line as worked between two comparatively busy magneto or, as they are sometimes termed, "generator" exchanges.

At the "outgoing" end the bush of the jack (branching) is connected to a relay, which, when a plug is inserted, is actuated by the test battery. This cuts off the battery normally connected to the "A" or "tip" wire of the line. If break-jacks are used, the relay is not required, the battery

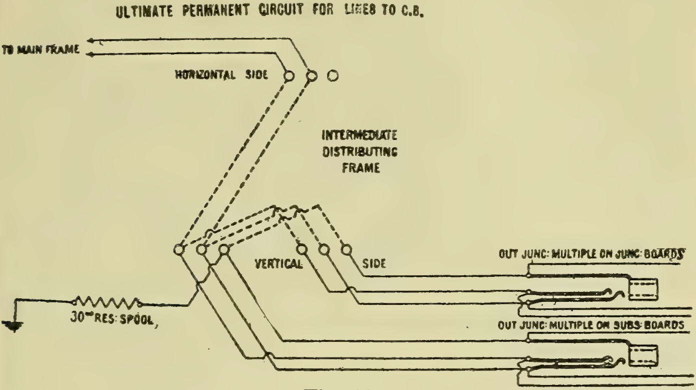


Fig. 261

being then directly connected to the inner contact spring of the "A" wire, as shown in dotted lines.

At the "incoming" end the line is connected through a listening and ringing key to the plug, but the "tip" wire connection passes through the inner contact and armature of a 250-ohm relay. This relay is actuated by the insertion of the plug into the jack of the called line, thus connecting the sleeve and the third conductor of the cord to earth. Under normal conditions the "tip" is connected through the outer contact of the relay through an order-wire transfer key to a tertiary winding of the operator's induction coil, so that the engaged test can be made through the tip of the plug without introducing an earth connection on to the ordinary line circuit. Directly the plug is inserted in the

jack, the test connection is cut off by the operation of the relay. The same relay when actuated puts an earth connection on the centre of a double-wound retardation coil of 1000 ohms total resistance, the connection passing through the coil of a "clearing" relay.

The called subscriber gives the clearing signal by ringing over the loop with his generator, this dropping the clearing

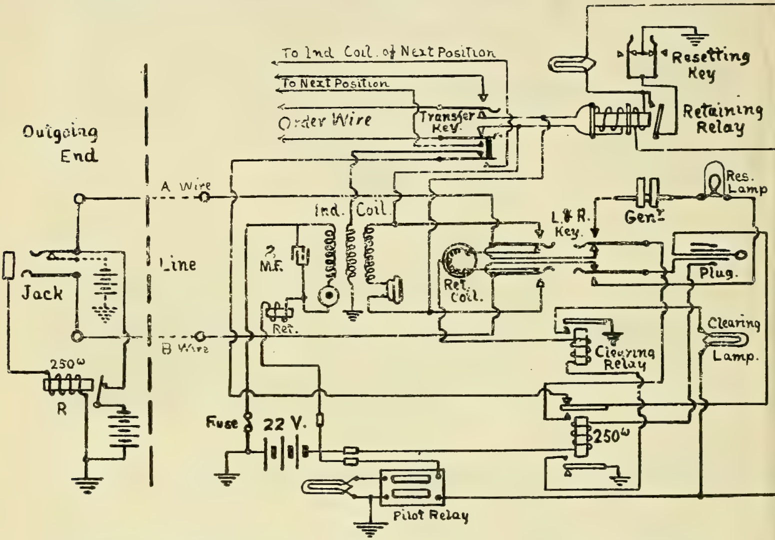


Fig. 262.—Order-Wire Junction between Magneto Exchanges

indicator at the "outgoing" or originating end, but not affecting the clearing relay at the incoming end of the junction line.

The operator at the "outgoing" end disconnects, and the armature of relay R completes the connection of the earthed battery to the "A" wire of the junction line. The current passes through one half of the retardation coil, and through the clearing relay, and causes the lighting of the clearing lamp. The "B" operator then disconnects. The withdrawal of the

plug causes a break in the 250-ohm relay, and the falling back of the armature breaks the circuit of the clearing battery at the outgoing end through the clearing relay at the incoming end.

It will thus be seen that the control of the connection is left with the "A" operator at the originating exchange.

The instructions for connection are, of course, given over the order wire, as already described, the connections of the order wire being also similar.

Ringing Junctions.—Fig. 263 gives the full connections at the incoming end of a junction wire which is used in conjunction with magneto exchanges having too few junction lines to warrant order-wire working.

The connections are somewhat similar to those of Fig. 262, except that under normal conditions a retaining relay is connected across the loop in addition to the double-wound retardation coil, and no special relay contact is needed in the "tip" conductor for the engaged test.

The connections at the outgoing end are also similar to those of Fig. 262.

The call is made by the "A" operator by generator current, as with an ordinary subscriber. This operates the retaining relay, which keeps the calling and clearing lamp, C.L., lit until the "B" operator answers by connecting her instrument to line by means of the listening key. The engaged test for the wanted line is made in the ordinary manner, and if the latter be disengaged the connection is completed and the subscriber called by ringing key. On insertion of the plug by the "B" operator, the 250-ohm relay is actuated as described in connection with Fig. 262. This cuts out the retaining relay, and puts earth on the coil of the clearing relay, C.R. The clearing operations are the same as in the last case.

Both-Way Junctions.—Where only one junction line is provided between two exchanges, or where it is considered of advantage to be able to work the junction lines provided, in both directions, it is necessary to have automatic signalling and clearing arrangements at each end, so as to work the lines to the utmost efficiency.

Equipotential System.—This is probably the simplest of the various arrangements for working both-way junctions, and is shown in Fig. 264. It will be seen that 7-point break-jacks are used at each end of the line, and that in the normal condition two equal batteries are connected to the line through two double-wound 100-ohm indicators, so as to be in opposition and neutralise each other, so that no current passes. When a plug is inserted at, say, the "A" exchange end, the battery at that end is cut off, and the battery at the "B" end becomes operative. Current passes through the two halves of the

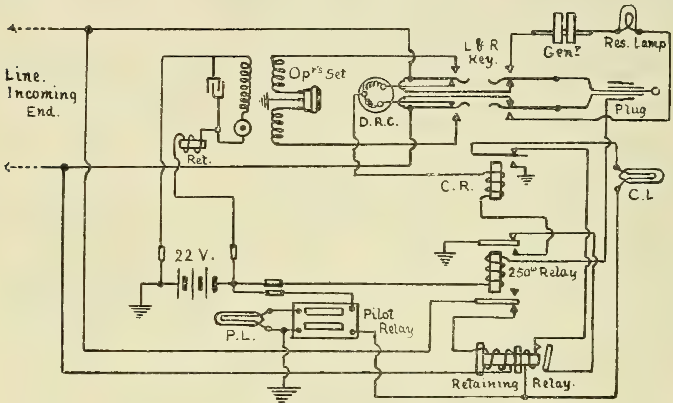


Fig. 263.—Ringing Junction between Magneto Exchanges

indicator, through both lines, the two halves of the double-wound retardation coil at the "A" exchange, the grid indicator, and to earth through the extra spring and contact of the jack. The operator at the "B" exchange being called by the falling of the 100-ohm indicator, plugs in, thus cutting off the battery, receives the instruction, and connects the wanted subscriber.

Clearing.—The ordinary clearing signals are provided in the operators' cord circuits at the two exchanges. An operator, on taking out the plug at one end, causes the actuation of the grid indicator at the other end by the current from the

battery at the far end, which remains connected until the line is cleared. The calling indicators should be of some self-restoring pattern, as they are actuated when a plug is withdrawn at the same end, and would, therefore, give trouble by needing restoration when the line was cleared.

The arrangement shown in the figure may also be worked in a different manner, the calling indicators being then wound differentially and connected up in such a manner that they are not actuated when the battery current splits through them. In such a case the signalling is done by generator current passing round the loop and through the calling drop.

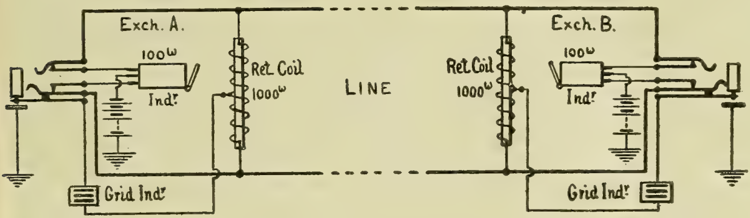


Fig. 264.—Both-Way Junction—Equipotential System

With such an arrangement the indicator will not be actuated when a plug is withdrawn in clearing.

The calling and grid indicators shown in the above arrangement may be replaced by relays, so as to adapt the system for lamp signals.

The above-described arrangements for both-way junctions are not very satisfactory in regard to speed of working; and if used in multiple exchanges they have another defect, inasmuch as no provision is made for putting the engaged test on the jacks when a line is connected at the distant exchange. It may thus happen that while an operator is calling on the line at one exchange another operator at the other multiple exchange may also plug into the line at some section, and call for some other connection in the opposite direction, thus giving rise to trouble and confusion. To overcome these difficulties somewhat complex circuits are necessary, and it

is, therefore, desirable to avoid this class of junction when possible.

Both-Way Ringing Junctions with Engaged Test.—Fig. 265 gives the connections of a "both-way ringing junction" between a magneto sub-exchange or private branch exchange and a multiple-magneto exchange, so arranged that an engaged test is put on the jacks at the multiple exchange on a ring being sent out from the sub-exchange. This is accomplished by using a differentially-wound relay with a retaining coil, D.R., in place of the usual differential retardation coil, connected across the loop at the multiple exchange. This relay is actuated by the ringing current from the sub-exchange, and closes a circuit in which is a double contact relay, L.R.,

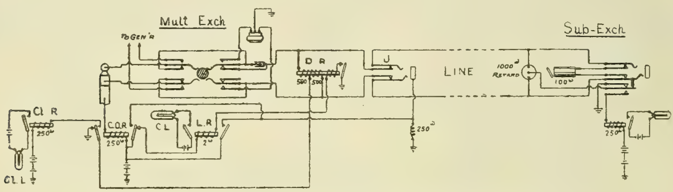


Fig. 265.—Both-Way Junction with Engaged Test

and an earthed battery, which lights the calling lamp, C.L., It also connects the earthed battery to the bushes of the multiple-jacks (of which only one J. is shown), so as to put on the engaged test. The cut-off relay, C.O.R. is of double make and break type, and when actuated by the insertion of the plug in the called-for subscriber's jack, connects up the clearing lamp Cl.L., to the centre of the differential coils of relay, D.R.

The other connections will be readily understood from previous descriptions.

Fig. 266 gives a photographic view of a section of the incoming junction switch-board at the "Barnsbury" Exchange. The section is made up of three operators' positions and eight jack panels in which the subscribers' jacks are multipled in

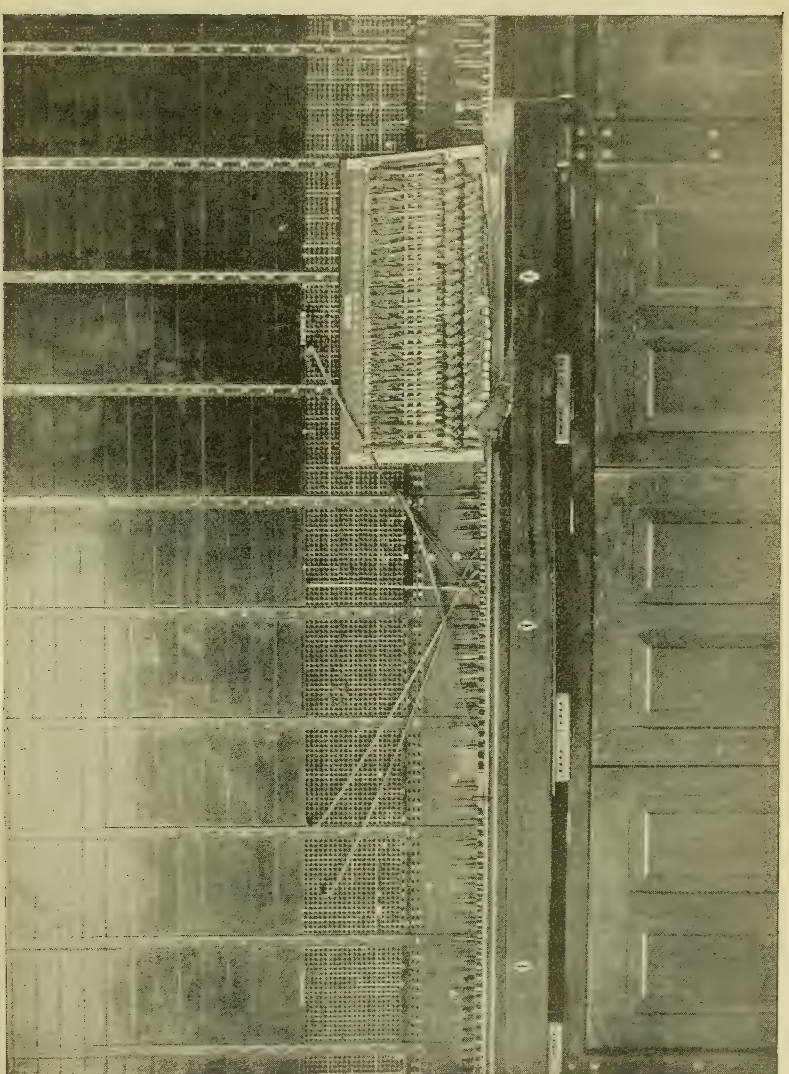


Fig. 266.—Junction Section

every six panels, so as to enable the "B" operators to easily reach every jack. As, with the exception of service-jacks, those for subscribers are the only jacks on the board, they can be fitted low down so as to be easily reached.

Each operator's position is fitted with twenty-seven cord circuits (which represent so many junction lines), each consisting of one plug and cord, one four-party machine ringing and listening key, one supervisory, and one clearing lamp. A common resetting and switching key is also fitted.

Junction-Line Grouping.—The efficiency of working of a junction-line is the greater when it forms one of a group of such lines working between the same two exchanges. The greater the number of lines there are in such a group the less the chance of every line being engaged when a connection is required, and therefore the less delay to subscribers in getting through. This advantage follows from the same principle which gives such benefit with "team working" in connection with operating (see page 326).

As the expense of providing a number of junctions is large, an important problem is to determine the minimum number of junctions to be provided between any two exchanges having a certain definite traffic per busiest hour, in order that there shall be not more than a certain maximum delay in getting through any one call. The N. T. Co. provide curves to determine such requirements.

CHAPTER XIX

TRUNK-LINE EXCHANGES *

SINCE the year 1896 the telephone "trunk" lines in this country have all been in the hands of the British Post Office authorities. By "trunk" lines is meant those lines used for communication between the exchanges of different telephonic districts, while the term "junction" line is confined to those lines joining the exchanges situated in the same telephonic district or area. In America a "trunk" line means the same as "junction" with us, and our "trunk" is called a "long-distance" or "toll" line.

The Post Office has provided trunk exchanges in all the large towns of the kingdom, and has constructed an elaborate system of trunk lines to join up all large and small towns. In the exchanges the lines are connected on to switch-boards specially designed for junction-line working, as nearly all the connections have to be made through junction lines joining the "trunk" exchange to the various ordinary local exchanges. The operating of trunk lines entails much trouble and attention on the part of the operators, so that but a small number of such lines are allotted to each operator during the busy parts of the day—five being the usual number in large centres.

Order-Wire Record Table.—A subscriber in a large local exchange desiring to speak to another in a distant town calls up his local operator and asks for a "trunk" connection. The operator immediately connects him to one of several "trunk-record" lines on which he is answered by an operator sitting at a "trunk-record table" in the trunk exchange. This operator writes out a ticket recording the number and town of

* See also Chap. XXX. for later modifications and improvements in trunk-line working.

the wanted subscriber, and also that of the calling subscriber, and then clears the record line. The record ticket is next passed on to the proper section of the trunk switch-board, and the operator attends to it when the line is at liberty, in the order in which the call was received. When the trunk line is free (or the call "matures") the operator connects to it, and instructs the distant operator to connect the desired number. She then immediately speaks to the local exchange, and instructs the junction operator to connect the calling number. The junction-line operator then sees that the conversation is commenced before cutting herself out.

The above is the most general method of working, but in

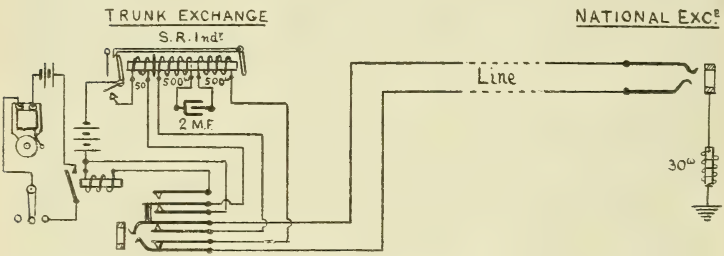


Fig. 267

cases where an order wire is not used the "record" lines may be worked on one of the ordinary junction methods similar to that shown in Fig 264, the signalling and clearing being automatic. In other cases the record lines are signalled by key, etc., as below.

Ringing Record Circuit.—Fig 267 gives the connections of a ringing record circuit line between a "trunk" exchange and a small common battery local exchange. Operator at "local" exchange connects the calling line requiring "trunk" connection to record-line jack by ordinary double cord and calls by generator. This actuates the double-wound self-restoring indicator, S.R.I., through condenser. The trunk operator tabulates the demand, and pulls out her plug, when the circuit

is opened through the condenser, causing the supervisory lamp at the local exchange to light up. On seeing this the operator clears connection.

Lamp Flashing.—If it should happen that, when tested, the line of a " wanted " subscriber is found to be engaged with a local line, the junction operator plugs in, and informs the subscriber that he is wanted on a trunk line. If he refuses to take the call at the time the subscriber at the distant end is charged for the call as if completed. If, on the other hand, he consents, the operator takes out her plug, and inserts a special " flashing " plug, which causes an intermittent flashing of the clearing lamp at the section at which the local connection is made. This attracts the attention of the local operator, who, knowing what it signifies, at once plugs in, and informs the subscriber that he is wanted for a trunk-line call. The disconnecting of the local connection causes a lamp to light on the trunk-junction position, and the operator there and then completes the connection to the trunk exchange.

If the line wanted had happened to be already engaged to a trunk line, the junction-line operator would have noted a characteristic " tone " test when the bush was tapped. In such a case the line is not disturbed, and the second trunk call could not be completed at that time.

London Trunk Exchange.—The principal trunk exchange in the kingdom is situated in Carter Lane, London, on a floor of the building immediately below the main portion of the " Central " telephone exchange of the Post Office, which is the largest local exchange in the kingdom. There are 21 sections of the trunk-line switch-board, each providing two operating positions, or a total of 42 positions. Each section of the board is made up of three panels, as shown in Fig. 268. During the busiest part of the day each operator attends to 5 trunk lines, but provision is made so that all these trunks lines may be " concentrated " on to certain special sections of the board, so that fewer operators may be needed to attend during the slack hours of the day and night. Such " concentration " sections may thus have, in addition to their normal number of 10

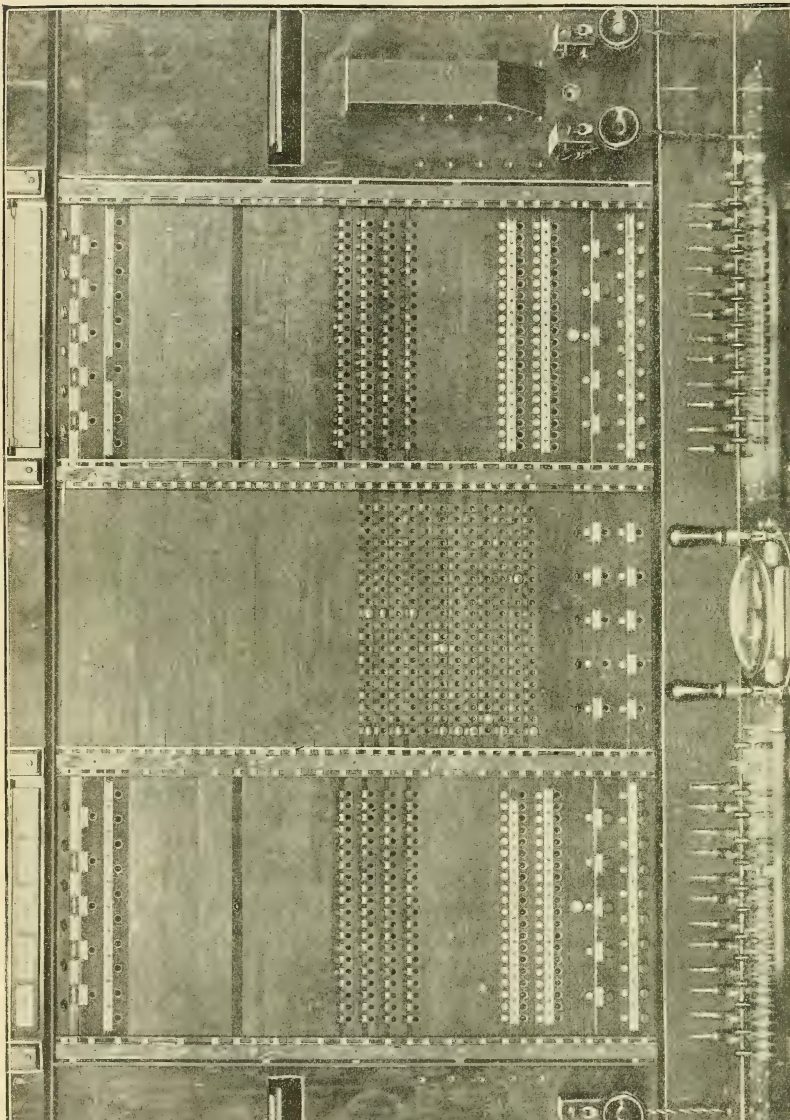


Fig. 268.—Trunk-Line Section

trunk lines, a further number, up to 20, terminated on them.

Fig. 269 gives the connections of a trunk line from the chief London trunk exchange to a provincial trunk exchange. It will be seen that the connections at the London end are somewhat complicated, this being necessitated by the concentration arrangements, and the fact that provision has to be made for connections to exchanges working on a variety of systems.

At the London end the trunk line is connected in parallel to the main line springs of two 7-point jacks (marked No. 1), the inner contact springs of these being connected (also in parallel), through retardation coils, to a main central 24-volt battery. A differentially-wound calling relay, R7, with a condenser inserted between the two windings, is also shunted across the line wires. Only one of the two line-jacks is in use at any one time, the other one always having the line springs lifted from contact by means of an insulating plug. The two jacks may be some distance apart from each other. Associated with each line-jack is another 7-point jack (No. 2), used for auxiliary purposes—connecting up the calling lamp, pilot lamp, etc. The auxiliary-jack is always plugged up with an insulating plug when its companion line-jack is in use. One pair of jacks is fitted on one of the ordinary sections, and the other on one of the "concentration" sections.

At the provincial exchange end the line is also connected to a 7-point jack, the inner contact springs of such jack being connected through the two windings of a differentially-wound relay (R8) to a 24-volt battery (20 v. and 4 v.). In place of a calling lamp a polarised indicating relay (P.I.R.) is used, the indicating needle (N) of which is, under normal conditions, kept deflected to the right by the 4-volt battery (4 v.). It will be noticed that at both ends of the trunk line, connection is made to a 24-volt battery, in such a manner that each battery opposes the other. No current, therefore, passes until a connecting plug is inserted in a jack at one end, when the battery at that end is cut off, and the battery at the opposite end becomes effective if a circuit is formed. This is the

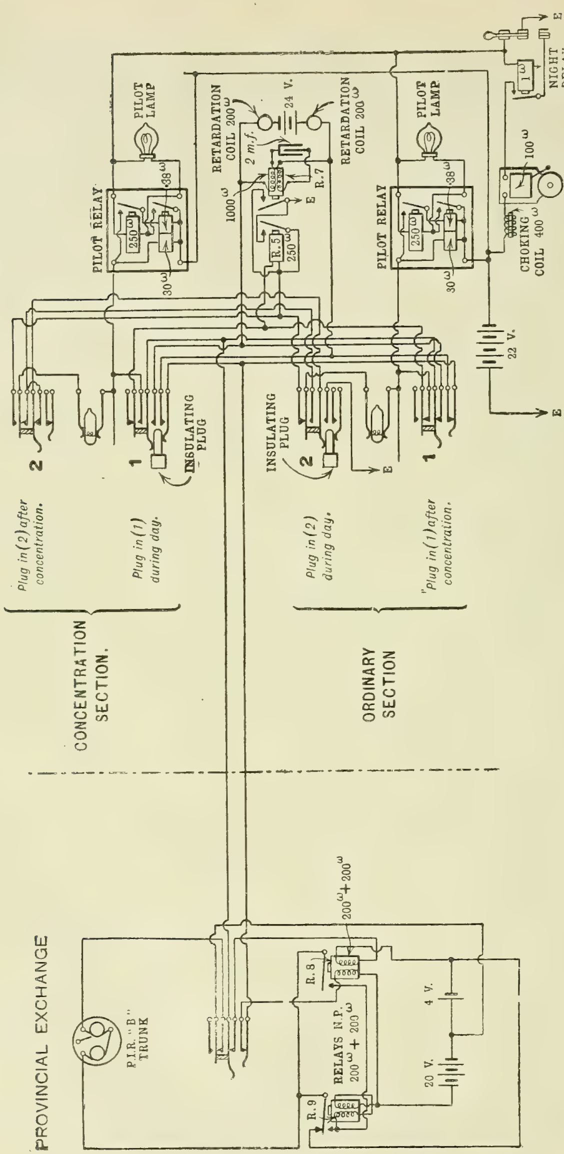

LONDON
PILOT LAMP
PILOT RELAY
RETARDATION COIL 200ω
24 V.
2 m.f.
1000ω
R. 7
R. 5
250ω
38ω
30ω
E
NIGHT RELAY
1ω
100ω
NIGHT BELL
CHOKING COIL 400ω
22 V.
INSULATING PLUG
Plug in (2) after concentration.
Plug in (1) during day.
Plug in (2) during day.
Plug in (1) after concentration.
CONCENTRATION SECTION.
ORDINARY SECTION
PROVINCIAL EXCHANGE
P.I.R. "B" TRUNK
R. 8
R. 9
200ω + 200ω
RELAYS N.P. 200ω + 200ω
4 V.
20 V.

Fig. 269

"equipotential" method of working, which was described in the preceding chapter, as used on "both-way" junction lines.

Method of Working.—When London wishes to call the provincial exchange a plug is inserted in the jack. This cuts off the permanent battery. A ringing key (S in Fig. 270) is then pressed, which connects another 24-volt battery in the reverse direction, so as to assist the battery at the far-end of the line. This operates the relay R8, which is so biassed as not to operate with a 24-volt battery. The R8 relay causes the operation of the R9 retaining relay by closing the circuit of a 20-volt battery through it, and the latter relay cuts off the 4-volt battery from the indicator, P.I.R. The needle of the latter is caused to deflect to the left by current from the 20-volt battery, thus attracting the attention of the operator. When the latter inserts an answering plug, the circuit through P.I.R. is broken, and the needle returns to its centre position, where it remains as long as a connection is made.

When the conversation is finished the clearing signal is given in the local exchange by the subscriber. The local exchange operator withdraws the junction plug, causing a lamp or other indicator at the trunk exchange to give the clearing signal. The trunk operator then pulls out the plug from the trunk line, and the 24-volt battery is again connected to the line, the current from it either deflecting a needle indicator connected across the cord at a provincial exchange end, or, if the latter clears first, causing the actuation of a 1000-ohm clearing lamp relay connected as a shunt across the connecting-cord conductors at the London end, as shown at R in Fig. 270, which shows the

Operators' Cord Connections at the London Trunk Exchange. A black plug is used for the trunk line, and a red one for the junction line or a second trunk line, the corresponding clearing lamps being coloured white and red. Two operators' keys are provided for each pair of cords—one a combined ringing and speaking key for use on the trunk lines, and the other a ringing and disconnecting key for use on the junction lines, the disconnecting part being provided to enable the operator to

disconnect the junction line, and so obtain more favourable

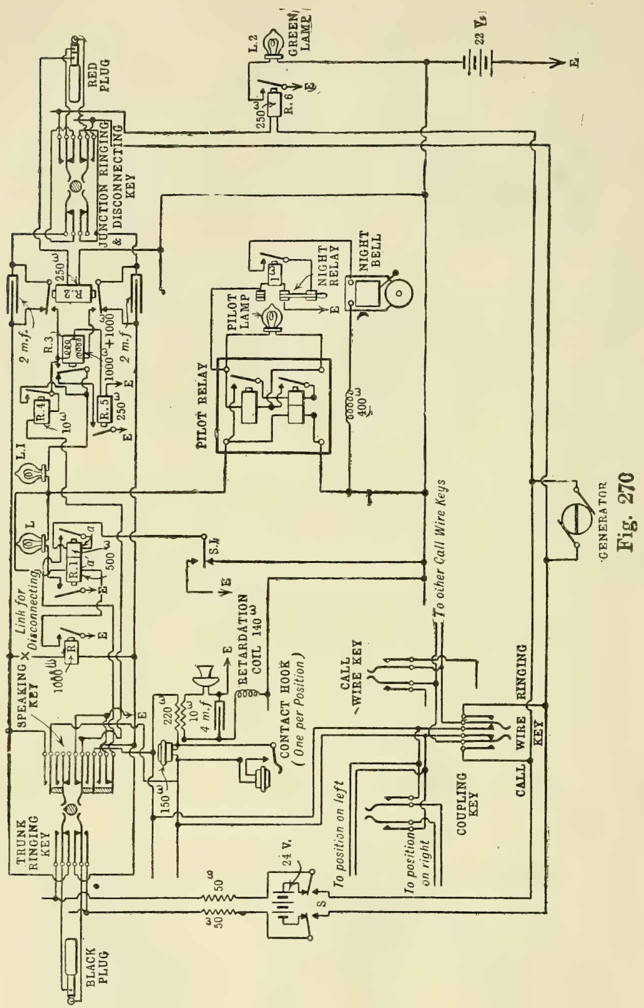


Fig. 270

conditions for speaking on long trunk lines. For similar reasons an extra receiver is provided for each operator. This,

when not required, is hung on a hook, which disconnects it, as shown.

The relay R1 works in conjunction with relay R for closing the circuit of the clearing lamp L at night when the permanent current is taken off.

On the junction line side the connections are similar to those of the ordinary C.B. junction line, a 3-point plug being used, the sleeve of which is connected to a double cut-off relay, R2, which when operated connects the clearing lamp relay R3 as a shunt across the junction line, the connection to the trunk line being made through two 2-microfarad condensers.

When connection is made to a second trunk line, the cut-off relay is not operated, and direct connection is made between the lines, the condensers being then short-circuited, as shown in the figure.

There are also the usual arrangements of pilot relay and lamps, night bells, etc.

During the slack hours of the night, etc., the equipotential system of working and signalling on the trunk lines is discarded, and the signalling is done by magneto-generators, the switch S being then thrown over on to the generator contacts. The other switch, S1, is also moved over so as to connect one end of a retaining coil on relay R1 to earth, so that if relay R gets a momentary signal current the retaining coil of R1 causes the lighting of lamp, L, until the circuit is interrupted by the trunk line speaking key.

Order-Wire Working.—Where there is a large amount of traffic between two towns, such as in the case of Manchester and Liverpool, or Glasgow and Edinburgh, the trunk lines are divided into incoming and outgoing lines, and one or more set aside as "order wires," and the traffic is then worked on the ordinary junction-line systems, as described in the last chapter.*

Trunk Junction Lines.—These are of two types, the first being "order-wire junctions," which are used to connect to the principal exchanges. These junction lines are fitted in the central panels of the trunk sections, and are multipled

* See also Chapter XXX. for telegraph-order-wire working.

throughout the board. The number of the line to be used is given by the incoming-junction operator at the local exchange, so that no engaged test is necessary. Figs. 271 and 272 show the connections at the trunk exchange or outgoing end of

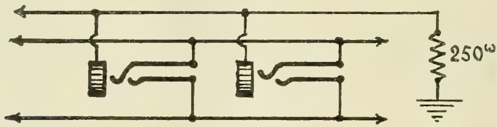


Fig. 271

junctions to C.B. and magneto exchanges respectively. The lines for the latter, it will be observed, have a cut-off relay for disconnecting the earthed battery, which is connected when the line is not in use. The connections of the junctions

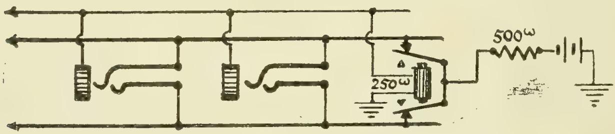


Fig. 272

at the incoming local exchange end are similar to those of the ordinary incoming junctions. See Chapter XIX.

The other type of junction is the ringing junction line, used to connect to small magneto exchanges where not more

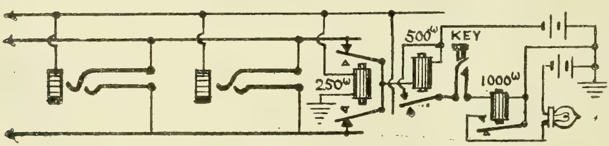


Fig. 273

than five trunk junctions are provided. The connections of one of these lines are shown in Fig. 273. They are multipled throughout the sections, and in addition are provided with an engaged test, which takes the form of a small press button

having relay and lamp associated with each jack. The jacks and buttons are fitted in the centre of each of the outside panels of a section. On pressing one of the buttons a special red lamp (common to an operator's position) is lit if the line is engaged. Having found a disengaged junction, the trunk operator plugs in, automatically lights a lamp at the far end, and thus calls the attention of the local exchange operator.

Calculagraph.—Each of the trunk sections is fitted with a piece of mechanism for timing the calls when connected, and for indicating the lapsed time during connection. It has a clock face and two handles, and is fitted in the centre of the key shelf of each section, as shown in Fig. 268. When a call has "matured," and the lines are connected, the record ticket

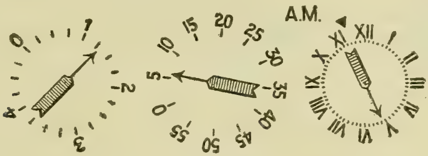


Fig. 274

is put in a slot under the clock face, and the right-hand handle, which has two movements, a front and a back, is pushed back. This prints a dial diagram, with triangular dot showing the hour, and an arrow showing the minutes of the day the connection was made, as shown on the right of Fig. 274. The operator then pulls the same handle forward, and impresses the two left-hand dials *only* on the ticket, *without the arrows.* The left-hand dial of the mechanism revolves once in five minutes, and the middle dial once per hour, with the arrows *always* pointing to 0. The arrows of these two dials are impressed only by the left-hand handle lever, so that when the conversation is finished, and the ticket is again put in the slot, and the missing arrows are stamped by the left-hand handle, the minutes elapsed since the first stamping are shown. Fig. 274 shows that the connection was made at 11.26, and lasted for $5 + 1\frac{1}{4} = 6\frac{1}{4}$ minutes.

Fig. 275, copied from the *American Telephone Journal*, shows the stamping mechanism, which is very ingenious, and has

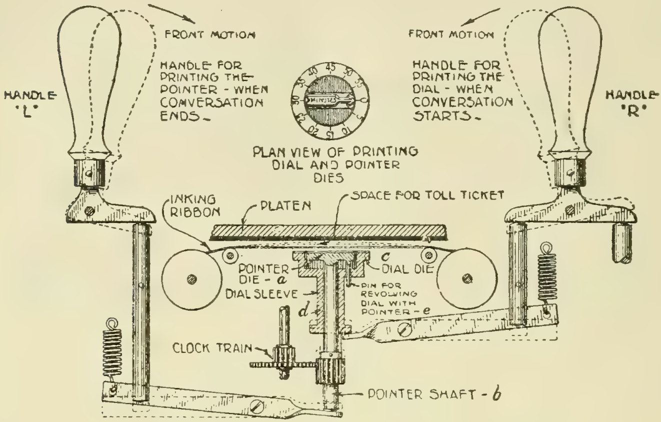


Fig. 275

proved of much service. Its working will be readily understood from the above description.

See also Chapter XXX. for modifications of above systems and later improvements in trunk-line working.

CHAPTER XX

PARTY-LINE WORKING

In order to lessen the subscription rate to those who only wish for occasional use of their telephones, arrangement is made so that two or more different exchange subscribers' instruments may be joined on to a common or "party" line.

Many so-called "selective" systems have been devised for working such "party" lines, so as to enable any one subscriber to call up or be signalled without disturbing the remaining stations, and also to prevent the conversation of one being overheard at the others. Very few, if any, of such devices have, however, proved perfectly successful in practice, the complications introduced having rendered the instruments more liable to faults and trouble. For this reason such arrangements have not been much used in this country, simplicity and reliability being looked upon as the main desiderata.

The saving in cost of party-line working is the greater the longer the line, as, in the case of a short line, its cost bears but a small proportion to the value of the rest of the plant that must be provided, so that but little advantage is gained.

National Telephone Co.'s System.—Fig. 276 shows one of the methods of working party lines used by the National Telephone Co. in this country. Four stations are shown connected to one line, and it is hence termed a "4-party" line. Sometimes ten or as many as twenty stations are connected on a single line.

The instruments are worked on the common-battery and automatic signalling plan, the annunciator (or line relay) being operated and the calling lamp lit at the exchange, when

any one of the subscribers removes his receiver, and thus closes the loop circuit to the battery. It will be noticed that two of the magneto-instrument bells are connected to the "A" wire of the loop and to earth. The other two bells are connected to the "B" wire, and to condensers (of about 2 microfarads capacity), the other terminals of the condensers being earthed. These condensers are used in order to prevent the closing of the loop circuit through the two sets of bells and the earth connections, which would result in the operation of the line relays and lamps. The same object may be attained by

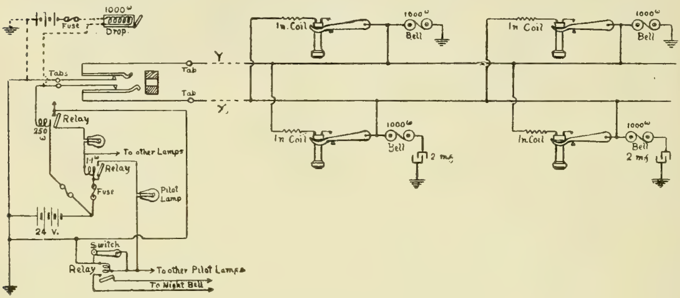


Fig. 276

raising the resistance of the bell branches to a very high figure, such as 20,000 ohms, or more, so that the current passing through the line relay is insufficient to actuate it.

The stations having their bells connected to the A wire are designated by having X and 1, 2, 3, 4, or 5 added to their ordinary line number and those connected to the B wire have Y and 1, 2, 3, 4, or 5 also added. The stations are called by code, a number of rings being given corresponding to their number on the wire—all the bells of the stations connected to the same leg of the loop being rung at the same time, those on the other leg being undisturbed. The X station bells are rung by the regular ringing key of an ordinary C.B. switch-board, but the Y stations require the con-

nections to be reversed, so as to connect the generator to the B wire of the loop. This is done by a second ringing key, as

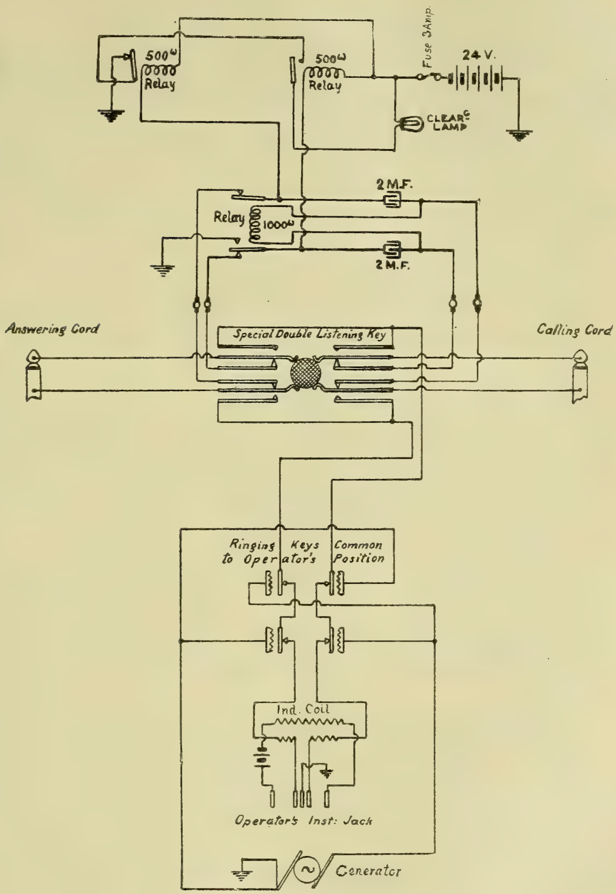


Fig. 277

seen in Fig. 277 (which shows the cord connections of a special party-line switch-board), or by the "generator reversing key,"

shown in Fig. 243, which shows an ordinary C.B. board cord-connections, arranged also for party-line working.

It will be obvious that subscribers on such party lines must put up with some inconvenience, in the shape of overhearing, delays, from the line being engaged by other stations, etc. These inconveniences are, however, much reduced when only two stations are connected to the line, one to each leg, as only the bell of the station wanted need then be rung in calling, and there is but little delay in getting a connection. This constitutes the "2-party" line, which gives much more satisfaction. The 4-party line is also much in favour, in which case two subscribers only are connected on each leg of the loop.

Selective Systems.—The many methods devised for selective signalling on party lines may be divided into the following groups :—

(1) "Step-by-step" systems, in which clock movements at each station are either released or driven synchronously by electro-magnets, and cause the revolution of a disc, which renders the bells inoperative except at some one point, which point is different for each station on the line.

(2) "Harmonic" systems, in which pendulums or reeds are made to vibrate, and to cause a bell to ring when current waves or interrupted currents of the proper rate or "frequency" are sent through the line—each station's ringing apparatus on one line being tuned to respond to a different rate of current vibration.

(3) "Current Strength Method."—Bells or relays are adapted to respond only to a certain strength of current, which can be varied for the different stations.

(4) "Polarised" bells or relays, responding only to currents in a certain direction.

(5) "Multiplex circuit" system, in which various combinations of the two wires of a loop and an earth connection are formed and connected to the ringing apparatus of the various stations.

(6) "Inductance and Condenser" system, in which the

several bells or relay circuits are so modified by the addition of inductance coils and condensers that some of the bells only respond to a weak and high frequency current, and others only to a stronger and lower frequency current.

(7) The "Wheatstone Bridge" method, in which a rheostat or adjustable resistance at the exchange enables the operator to so adjust the resistances of the line circuit that all the bells except that of the station required may be cut out or short-circuited.

So far systems Nos. 2, 4, 5, and 6, or combinations of these,

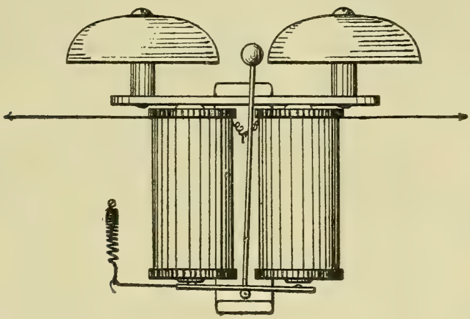


Fig. 278

have proved the most promising in practice, and a short description will now be given of two or three arrangements which have proved specially promising.

The Hibbard System.—This, which is extensively used in America, is based on Nos. 4 and 5 methods. "Biassed" polarised bells are used. This form of bell is an ordinary ringer, whose armature is fitted with a light spring, so that in its normal condition it is drawn down on to one pole, as shown in Fig. 278. With unidirectional current such bells will only respond to either positive or negative direction of current according to which side of the armature the spring is attached.

Two stations fitted with oppositely biassed bells are con-

nected to each leg of the loop and to earth, as shown in Fig. 279, thus making a 4-party line. The calling is done from the central by a series of four ringing keys, on pressing any one of which the appropriate unidirectional vibratory current from a commutated alternating generator or interrupted battery is connected on to the proper leg of the line to operate the bell of the required station.

Alternating current cannot be used for ringing on these lines, as both bells on the leg would be rung; and condensers cannot be used in the bell circuits (as in the National Telephone Co.'s party-line system), as a unidirectional current sent through a condenser is converted into an alternating current by the charges and discharges. If, therefore, automatic signalling is

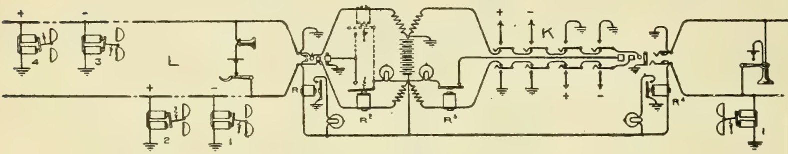


Fig. 279

required, it is necessary to make the bell branch to earth, of a very high resistance, so that the current passing through is insufficient to operate the line relay, for which reason the bells are wound to about 2500 ohms, and a resistance coil of from 5000 to 20,000 ohms is added to the circuit. This high resistance reduces the loudness of the ring of the biassed bells, and the shunt gives rise to a continuous leakage of the common-battery current to earth. In a large system such leakage may become a serious item in the maintenance cost. The direct connection to earth of the lines is also objectionable, as it gives rise to troubles from the unbalancing of the lines, and for other reasons. For such reasons the condenser method of ringing is much preferable when it can be used.

Thomson & Robe's System.—This is a modification of the Hibbard system, designed to dispense with the need for direct earth connections on the lines.

Under normal conditions the bells are totally disconnected from the line circuits, and are connected only when required to be rung, by means of relays inserted in branches from the

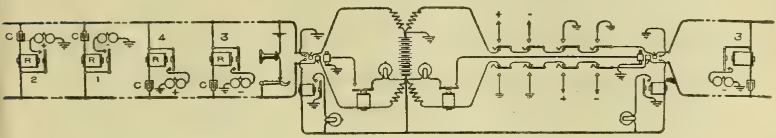


Fig. 280

loops, with condensers, as shown in Fig. 280. These relays having heavy slowly-moving armatures are operated by ordinary alternating currents sent through the loop, and while so energised, and the bells thereby connected through the contacts, the appropriate unidirectional pulsatory current is superimposed on the proper leg of the line to ring the bell of the subscriber required, through the relay contact and earth connection.

Fig. 280 also shows the combination of ringing keys used by the operator for ringing on a line connected on the right-hand side.

This arrangement, though a great improvement for common-battery working, still retains many of the faults of the Hibbard system, with added complication at the sub-station, where it is most objectionable.

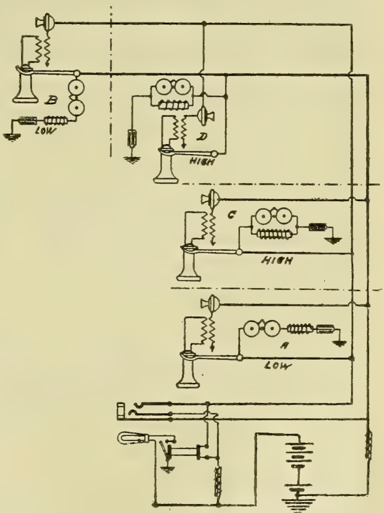


Fig. 281

The Leich System.—This "4-party" line system is based

upon the principle that the impedance of a retardation coil varies *directly* as the square of the frequency of the current waves traversing it, while the impedance of a condenser varies *inversely* as the square of the frequency.

Fig. 281 gives the connections of a 4-party line. Two ordinary polarised bells are joined to the A wire and two to the B wire of the 4-party line and to earth. One bell (1000ʷ) of each pair is joined directly in series with a retardation coil (2000ʷ) and a condenser (2mf.), and the other bells (1000ʷ) are shunted by a retardation coil (1000ʷ) and also a condenser (·3mf.) in series.

Alternating currents of two frequencies are used for ringing —one of about 2400 alternations per minute, and the other of about 7200 alternations per minute, or three times as high. The bells first mentioned are rung only by the low-frequency current, which also passes through the other bell connected to the same leg; but as the condenser is of comparatively small capacity, and as most of the current which passes goes through the comparatively low-resistance retardation-coil shunt, the bell is not rung. On the other hand, the high-frequency current operates the latter bells, as it passes easily through the condenser (apparently), and most of it passes through the bell coils, as the shunt offers great impedance to the high-frequency currents, while the impedance coil, in series with the other bells, prevents sufficient current passing to actuate the bell.

This is claimed to be one of the most successful systems yet devised, and as the earths are all cut off from direct connection with the lines, ordinary C.B. working is not interfered with.

The Dean System.—This is a 2, 3, or 4 party device lately introduced, for which many claims are made with regard to its simplicity, and the fact that no earth connections are needed to the line. It is based on the harmonic (No. 2) system, and uses special polarised ringers, the armatures of which are attached to short, stiff springs fixed at one end, and so forming comparatively heavy reeds, which vibrate between double coil-magnet pole-pieces. The free end of each of the armatures is weighted with a metal ball or cylinder, each of the four

on a party line having a ball or cylinder of different size and weight. These are set in vibration, and strike the single-bell dome only when the alternating currents passing through the coils have a frequency, for the smallest ball, of 8000 alternations per minute, and of 6000, 4000, and 2000

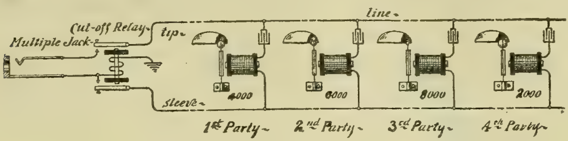


Fig. 282

respectively for the others—the latter number being for the heaviest ball.

Mr Dean has more recently introduced a modification in which the bells used are magneto ringers differing from the ordinary form in having their armatures fitted on a spring instead of being pivoted. In the normal position the arma-

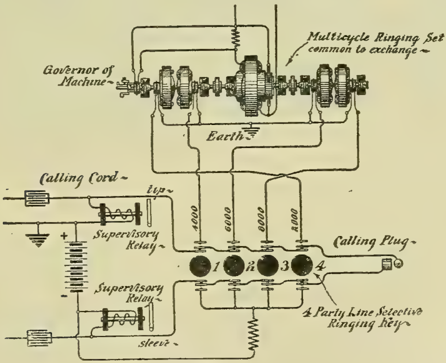


Fig. 283

ture is held by the spring midway between the poles. The hammers of the ringers are cylindrical bars of four different lengths. This form appears to be even more satisfactory than the one above described.

The bells of the four stations are connected to the line as shunts, with condensers in series, as shown in Fig. 282. The ringing generator for the production of the four different frequencies is shown in Fig. 283, which also shows the connections of the special 4-party ringing keys for sending out the different frequencies as applied on a switch-board on the

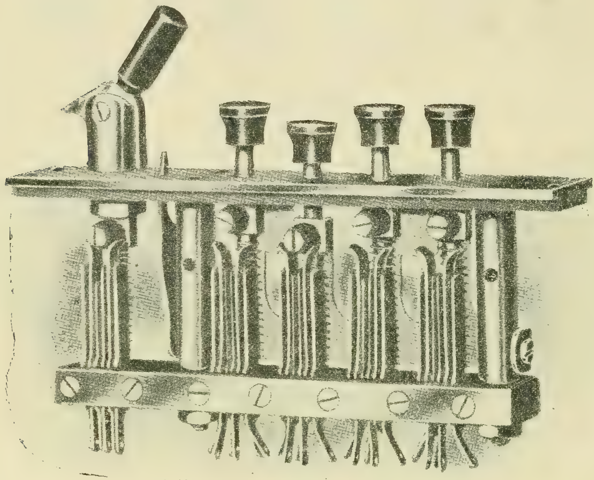


Fig. 284

Kellogg C.B. system. A view of the latter key, with a listening key attached, is shown in Fig. 284.

Indicating Party-Line Keys.—A rather important point in the practical working of these selective systems in exchanges is that some arrangement should be provided to show the operators which of the stations has been last rung, as it is sometimes necessary to give a second ring, and the operator is liable to forget which station was called for. The combined party-line ringing key, shown in Fig. 284, does this, the key which was last used remaining slightly depressed below

the general level when released until another key of the four is used, when it is raised to its normal position.

W. E. Co.'s Combination Key.—Another method of showing this, as used by the W. E. Co., is to use sectional sliding plates on the upper surface of the key. The last key used is shown by a red space left between the sectional sliding plates. Two

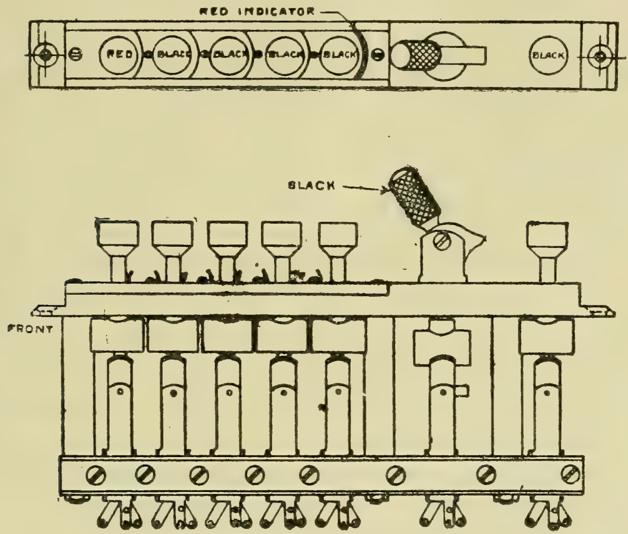


Fig. 284*a*.—4-Party and Direct Line Ringing and Listening Key

views of combined keys on this principle are shown in Fig. 284*a*. It is a combination of a 4-party, direct-ringing, service register and a listening key and has now been adopted for all the more modern switch-board equipments.

Efficiency of Party Lines.—With regard to the question as to the general efficiency of party lines, it is the general opinion of telephone engineers that 2-party or 4-party lines work well, and give little trouble, with moderately busy subscribers.

CHAPTER XXI

APPARATUS-ROOM

This is a room in which is fitted a large portion of the auxiliary apparatus required in connection with the switch-board. Such a room was formerly known as the "test-room," as a "*test-board*," fitted with "*test-jacks*" and other testing apparatus for the tracing or localising of faults on any of the lines, formed the chief feature in it. This "test-board" is now, however, dispensed with in the most up-to-date exchanges (except in connection with *private* lines, *order* lines, and *through junction* lines), as it is found more convenient to utilise one of the ordinary operator's positions on the switch-board for the purpose of testing most of the faults (about 95 per cent.), the others being tested at the arrester-board by means of a special connecting-jack, shown by Fig. 292.

In order to save cable in wiring, it is desirable that the apparatus-room shall be situated as near as possible to the switch-boards to be fitted—either at one end of, or, what is even better, on the floor immediately above or below, the switch-room.

Distributing Frames.—The lines from outside, whether overhead or underground, enter the exchange building in no particular order as regards their exchange numbers. It is, however, necessary that the lines on the switch-board in connection with the multiple-jacks shall be arranged in proper numerical order. It becomes necessary, therefore, to provide some means by which the irregularly-arranged lines from outside can be connected to the jacks on the switch-board in an orderly and neat manner, and so that such connections can be changed at any time—when, for example, a subscriber

removes to other premises in another part of the town and wishes to retain his switch-board number. To meet these requirements "distributing frames" are provided, on which terminals (generally in the form of soldering tabs) are fitted on one side or face. To these the lines from outside are attached, and on the other parallel side, separated by about 3 feet, another set of terminal tabs is fitted, to which wires are brought from the switch-board in numerical order. On one side of the frame the tabs are arranged in vertical rows, and on the other in horizontal rows, and the terminals on the two sides are joined together by what are termed *cross-connecting* or *jumper* wires, the frame between these being so constructed that these jumper wires can be conveniently run, without confusion, from any one pair of terminals on one side to any one pair on the other side. As above described, the whole arrangement is known as the *Main Distributinq Frame.*

Intermediate Distributing Frame.—In a modern multiple switch-board, in order to operate the switch-board with the greatest economy and efficiency, it is necessary to be able to *redistribute* the busy and slack subscribers' lines on the local or home part of the switch-board sections, so as to equalise the work of the operators without having to interfere with the ordinary numbers of the lines so moved. (See also Chapter XXIII.) This is accomplished by providing (for a branching-jack switch-board) another distributing frame between the main distributing frame and the switch-board, on one side of which wires from the main frame and from the multiple-jacks of the switch-board (which must always be kept in proper numerical order) are connected. On the other side, wires from the answering-jacks, the calling lamps, and line and cut-off relays, are connected, also arranged in regular numerical order. With "jumper" wires, any one set of tabs on one side may be connected to any one set on the other side, as on the "main" distributing-board.

It will be easy to see that, as the calling lamp of any line is kept in close proximity to its corresponding answering-jack

on the switch-board, it does not matter to the operator what is the actual number of a calling line so long as the jacks in the multiple field are kept in strict numerical order, so that any "called-for" line may be found at once.

This board is also found convenient for connecting to various pieces of apparatus, such as relays, registers, etc.

Fig. 285 gives a plan of a subscriber's line circuit in a C.B. Exchange, from which the connections to the distributing

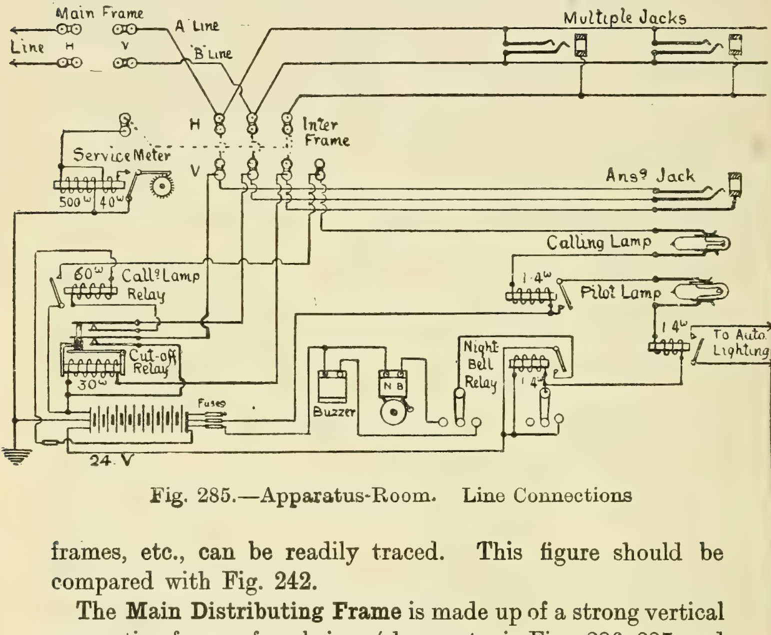


Fig. 285.—Apparatus-Room. Line Connections

frames, etc., can be readily traced. This figure should be compared with Fig. 242.

The **Main Distributing Frame** is made up of a strong vertical supporting frame of angle iron (shown at A in Figs. 286, 287, and 288), to which a large number of iron bars, V H, are fitted at right angles, so as to project on both sides of the supporting frame. On the ends of these bars brass cross-pieces, X, are riveted, and to these the terminal tab strips and arrester strips are screwed, so as to form horizontal rows on the H side and vertical rows on the V side. A view of four vertical rows

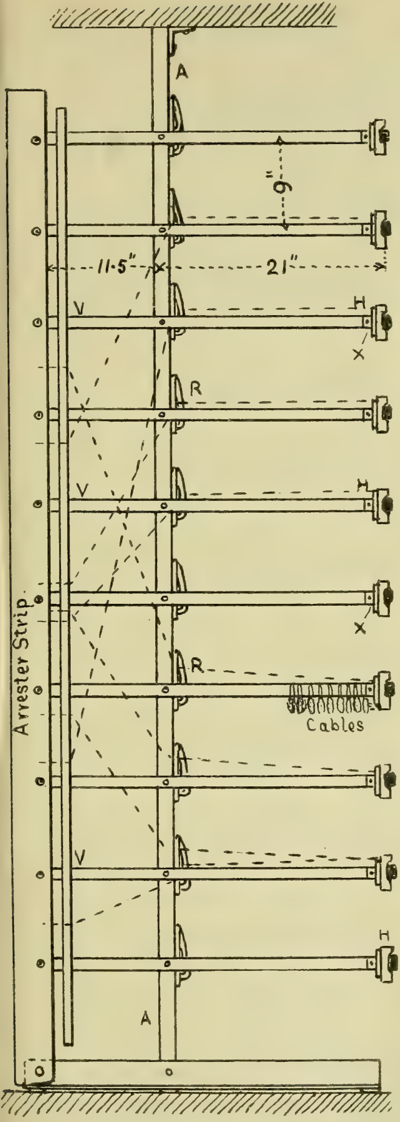


Fig. 286.—Scale $\frac{1}{12}$

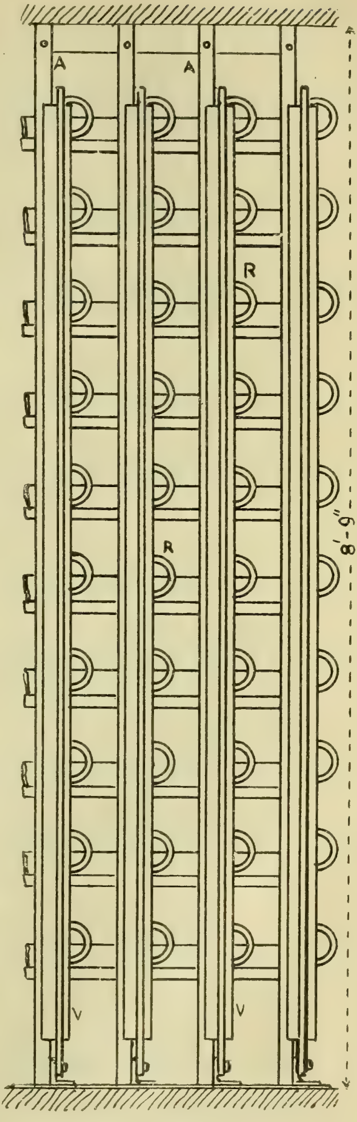
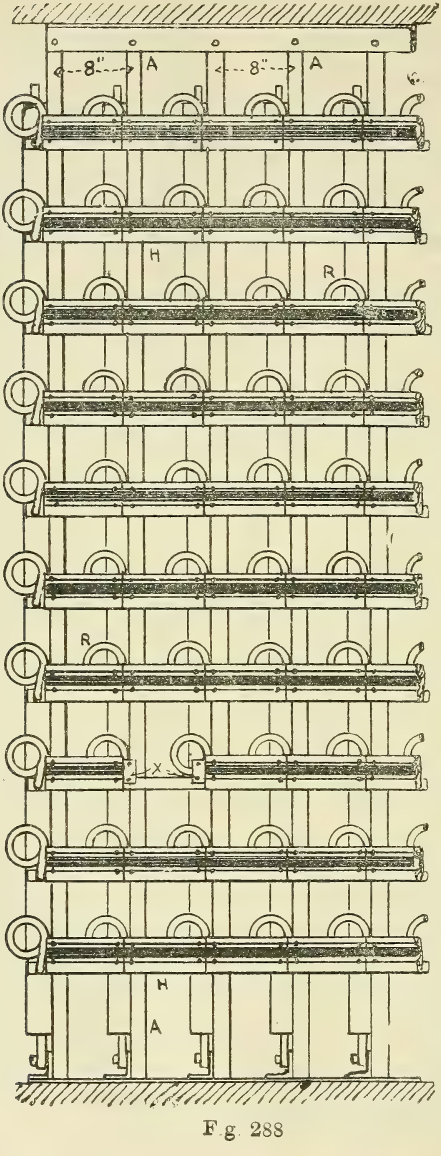


Fig. 287



F.g. 288

is shown in Fig. 286, and of a portion of the horizontal side in Fig. 288.

Line Terminal Side.—The terminal strips used on the horizontal side of the distributing frame, to which the incoming lines from outside are connected, are made in sections similar to that shown in Figs. 289 and 290, placed end to end, so as to form a long, continuous row. They are made up of brass stampings, of the shape shown, fixed in slits cut in a strip of ebonite, another ebonite strip being screwed down over them to keep them in place. The clamping screws pass through the strips to an iron strip at the bottom of a wooden base, in which a large number of holes are drilled for the connecting wires. The ends of the tabs are notched and tinned for soldering. Only two tabs are actually required on each stamping, but the extra one on alternate sides of the stampings is found convenient for testing, etc.

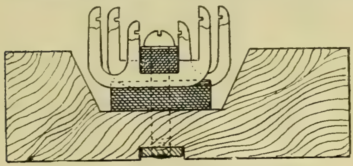


Fig. 289.—Section

Arrester Strips.—The vertical side of the main frame is fitted with strips of a combination of carbon lightning arresters, heat coils, and soldering tabs, mounted on a long iron bar, each strip of about 7½ feet in length providing for 180 lines. Fig. 291 is a section through a strip, showing the arrangement for a pair of wires. The carbon arresters are similar to those shown in Fig. 108, having the U-shaped mica and the plug of fusible metal. The *heat-coil* (seen in section) is placed between the springs as shown, the inner spring resting against a small brass collar soldered near the end of a thin brass rod by fusible metal. When the current in the coil becomes too great (more than ·33 ampere) the wire becomes heated, the fusible metal melts, and the outer spring then presses the whole coil inward until the end of the rod, passing through the collar, presses the light spring s against the German

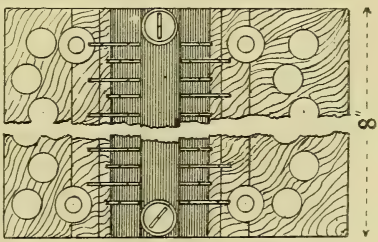


Fig. 290.—Plain Scale ½

silver strips, riveted on the thick iron bar, which forms the support for the whole strip.

The resistance of the heat coil is 3·75 ohms. All the bars are connected to earth, and thus the line wire becomes directly earthed when the fuse operates. The current through the line is at once strengthened, and the line fuse (fitted at the point where the lead joins the outside line) melts, and introduces a gap in the line circuit, cutting off the high voltage from every part of the internal circuit.

Latest Practice.—In the latest exchanges the line fuses are combined with the arrester strips as in Fig. 291*a*, which gives

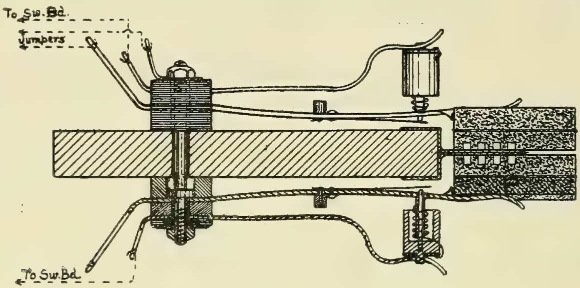


Fig. 291.—Scale ½

two views of the combination. The lines are connected first to the line fuses, then to the arresters, then by jumper wire to the horizontal frame and next to the I.D.F.

When a heat coil fuses, the corresponding line inside is earthed, and its lamp is lit on the switch-board; but as no communication can be obtained, the operator reports the line to the fault clerk.

For convenience of connecting the twin "jumper" wires, the clamping screw A is connected to one of the inner-line springs, but is otherwise insulated, and is furnished with a soldering tab on the opposite side of the frame plate, so that both jumper wires can be connected on one side.

Resetting Heat Coils.—In some recent forms of protector used in America the heat coils are so constructed that they can be used over and over again without repairs. In the "Kaisling" protector this is accomplished by making the heat coil symmetrical, so as to be reversible. When the coil has operated, and the pin has been pressed inward, all that is needed to reset is to reverse the coil, the pin having again become fixed, with its end projecting through the other end of the coil.

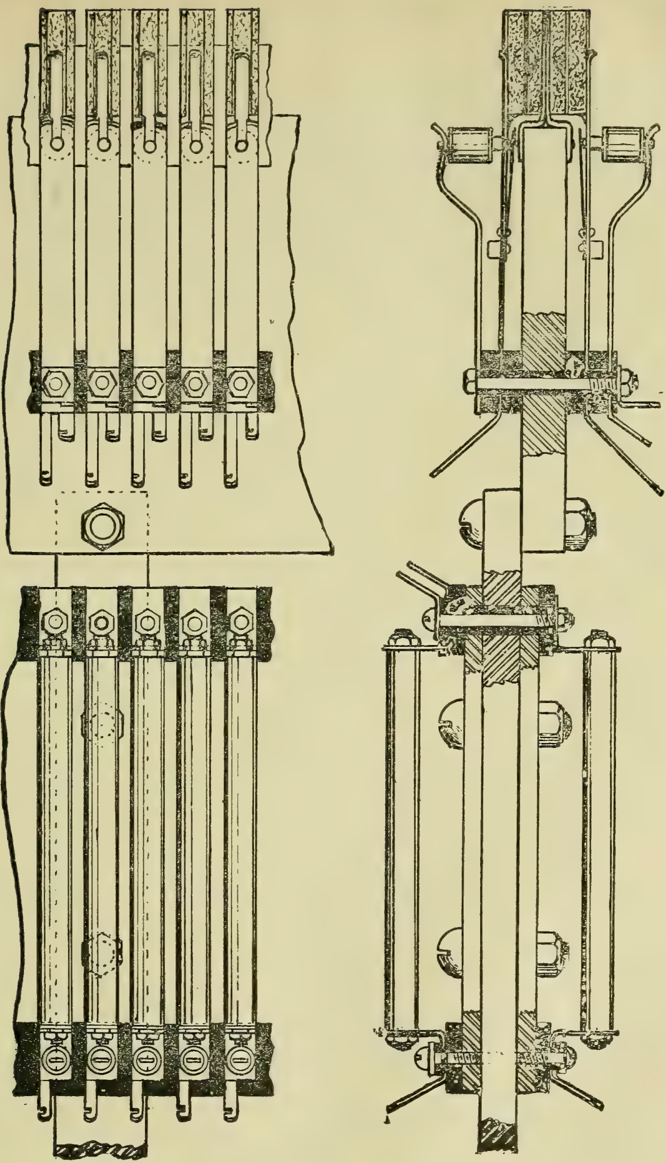


Fig. 291*a*

Side Elevation Plan

Main Frame. Combination Protector and Fuse Strips

In the "Cook" form the coil is pivoted, and is furnished with ratchet teeth. A spring is held outwards by one of these teeth, but when the solder melts the coil moves round, and the spring is released. The solder hardens, and all that is required to reset is to pull out the alarm spring until it is caught by another tooth of the ratchet.

Jumper Wires.—The "jumper" wires used on the main frame are twin No. 22 B.W.G., each wire being tinned and covered with rubber and cotton, the two wires having distinguishing colours. The outer covering is braided cotton, painted with asbestos paint to render it flame-proof. The wires used for ordinary subscribers' lines are covered white, those for junction lines red, and those for private lines black.

Cross-Connecting.—In connecting up, the jumper wires are soldered to the two inner spring tabs of the arresters; they pass through holes in the wooden channel strips at the back of the arrester bars, and then through one of the iron rings, R R (Fig. 287), the particular one used depending upon which row of tabs on the horizontal side the tab to be joined up is situated. After passing through the proper ring, the wire is carried in a diagonal line to the back of the particular tab to be connected. Fig. 287 shows in dotted lines the jumper wires radiating in a vertical plane from the iron rings, and the dotted lines in the plan of the main frame in Fig. 296 show the wires radiating in horizontal planes to the horizontal tab strips, the horizontal bars H V forming a shelf on one side for the support of these wires. The iron rings R R have an insulating covering of vulcanite to prevent possibility of earthing.

Testing at Arresters.—In localising faults, etc., it is sometimes necessary to make connections at the arrester strips. For this purpose a special *testing shoe* is used, shown in Fig. 292, this being joined by a 4-way cord to the test clerk's desk. The heat coils are first withdrawn from the arrester springs, and the test-shoe is slipped over so as to make contact with all four springs of the arrester.

This is rather a slow method of testing, but as only a small proportion (about 5 per cent.) of the faults need to be tested

in this manner the small loss of time is not of much consequence.

Intermediate Distributing Frame.—This is situated between the main frame and the switch-board. It is built similarly

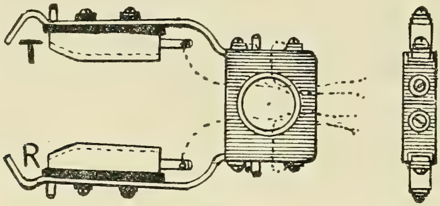


Fig. 292.—Testing Shoe

to the main frame, but need not be quite so large, as it is only necessary to provide for the lines actually to be fitted on the switch-board. It should, however, be built for the full capacity at first, as it is difficult to enlarge after installation. The terminal tabs on the side connected to the main frame are arranged

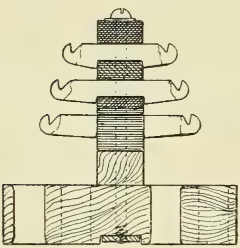


Fig. 293.—Scale ½

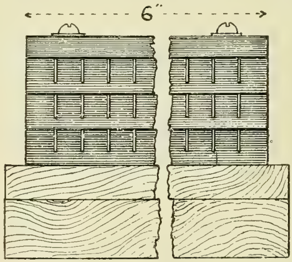


Fig. 294

horizontally, and provide for three wires per line. A sectional view is shown in Fig. 293, and a side elevation in Fig. 294.

On the vertical side similar sections of terminal tabs are used, but four tabs are provided for each line instead of three.

The " jumper " wire or cable used is triple, each of the three

constituent wires having a distinguishing colour, each colour being joined to corresponding tabs on the strips.

Cabling.—The leading-in cables jointed to the underground cables or overhead wires are carried in cable "runs" (which are troughs made of open ironwork), and are taken to a point just underneath the horizontal row on the "main" frame to which they are to be connected, being tied to, and below, the horizontal bars H V, as shown on the right of Fig. 286. The cables, which are mostly 214-pair silk and cotton covered wires with an outer covering of lead, are spliced to the underground dry-core cables and are then opened or "fanned" out in a manner similar to that used when joining cables to the multiple-jacks of the switch-board, and soldered to the under side of the tabs. In order to save cable, the end of the main frame should be as near as possible to the point where the cables enter the building.

The arrangement of the cable "runs" or "racks" for the connecting cables requires a good deal of consideration and inventiveness in order to provide for the "turning," etc., necessary owing to the different relative positions of the same cables at the two ends. Several good examples of "cabling" will be seen in the several photographic views of the "Barnsbury" apparatus-room shown in this and the next chapter.

On the arrester, or vertical, side of the main frame 42-wire cables are used to connect to the intermediate distributing frame. The wires in these cables are No. 22 gauge, insulated with a covering of silk and cotton, are twisted in pairs, and have distinguishing colours similar to the switch-board cables. The cables also have an outer flame-proof covering. After "fanning" out, the wires are passed through holes in wooden channel strips and soldered to the tabs connected to the outer springs of the arresters, the heat coils connecting to the inner springs. The cables are tied in vertical rows to the left-hand side of the horizontal supporting bars of the frame.

From the horizontal side of the intermediate frame 63-wire cables are used to connect to the multiple-jacks on the switch-board. A duplicate, or even triplicate, set of cables may be

joined to these tabs, one set going to the multiple-jacks on the subscribers' section of the switch-board and another set to the multiple-jacks fitted on the junction sections of the board

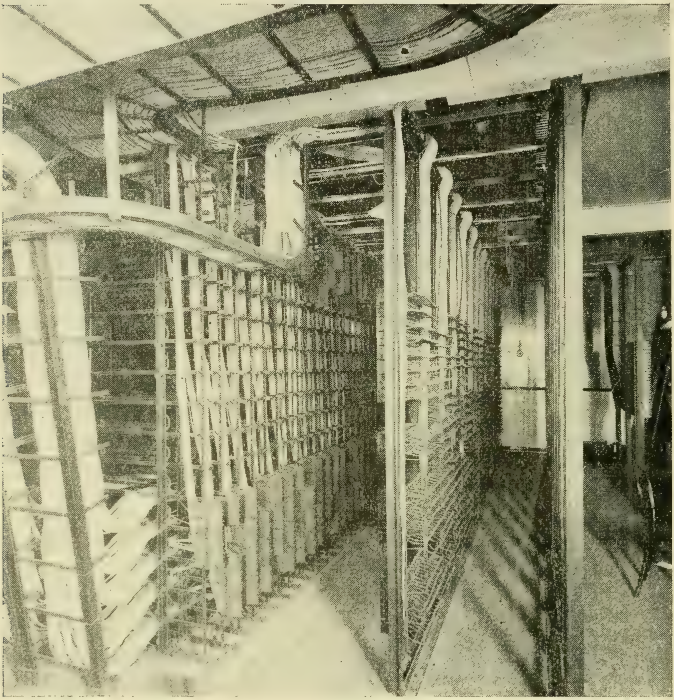


Fig. 295.—Intermediate Distributing Frame and Relay Racks

which, in large exchanges, are generally fitted apart from the subscribers' sections.

From the vertical side of the intermediate frame 84 wire cables are carried to answering-jacks and calling lamps of the various subscribers' sections of the switch-boards, each line requiring four wires—three to each jack and one to each lamp.

Relay Racks.—From the same tabs on the intermediate frame

a second set of 84 wire cables is carried overhead to two iron skeleton frames, fixed parallel to the intermediate frame (as shown on the photographic view Fig. 295), to the upright T section bars of which, fixed 20 inches apart, are screwed rows of 10 combined line and cut-off relays (see Fig. 188). Each of the rows is provided with a sheet-iron cover, which completely protects the relays from dust, etc. The connecting tabs project at the back, and the connecting cables are brought down the sides, and "formed" about 3 or 4 inches away, for greater ease of access and observation, as seen in the centre of Fig. 295.

Barnsbury Apparatus-Room.—Fig. 296 gives a plan of the apparatus-room at the National Telephone Co.'s "North" exchange at Barnsbury, London, showing the positions of the distributing-boards, relay and other racks, etc.

The underground conduits finish close up to the end of the main frame, which is 22 feet long. On the horizontal side it has 10 rows of connecting tabs, each row having 33 sections, each for 20 lines, thus providing for a total of $33 \times 20 \times 10 = 6600$ lines.

The vertical side has 33 rows of arresters, each for 180 lines, or a total of $33 \times 180 = 5940$ lines.

It is necessary to provide for a large excess of lines on the horizontal side, as terminals have to be provided not only for the actual working lines, but also for those lines which are spare. The latter generally amount to 30 or 40 per cent. of the total number of lines.

On the vertical side, which connects to the switch-board, it is only necessary to fit terminals for the number of lines actually in use, and as the arresters, etc., are comparatively very expensive, whilst the terminal tabs are cheap, a considerable saving in cost is attained over the system formerly in use in which the outside lines were terminated on the arrester bars.

Besides the subscribers' lines, the incoming and outgoing junction and other miscellaneous lines are also accommodated on the arrester frame, special bays being reserved for them, so as not to interfere with the numerical order of the subscribers' lines.

Private Lines.—The capacity of the vertical side of the main frame being in excess of the requirements for subscribers' lines, three of the end vertical bars of the frame are used for the

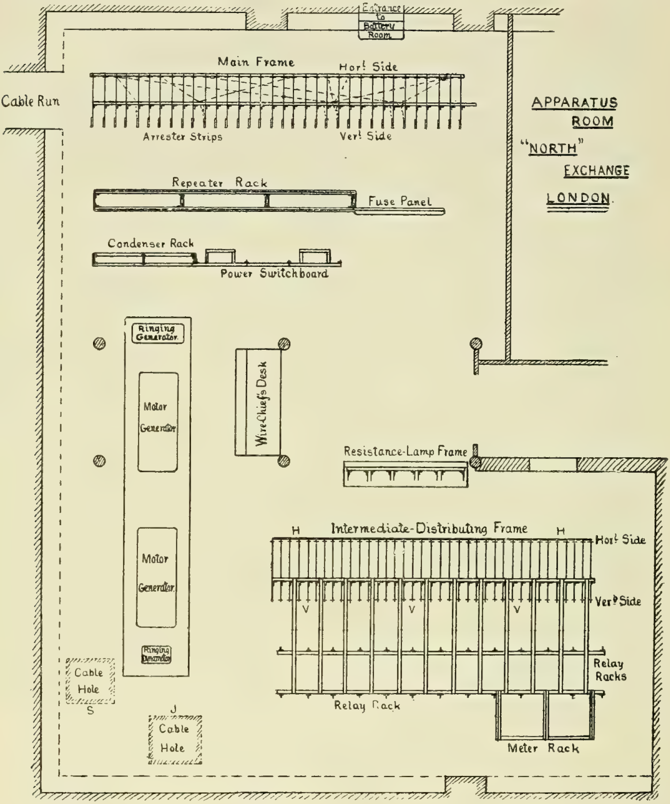


Fig. 296.—Scale about $\frac{1}{140}$

fixing of test-jacks, for the purpose of providing a means of testing a number of private lines, which are brought into the exchange for convenience of localising faults, etc. Each of such lines is connected from the horizontal side on to two 7-point break-jacks, as shown in Fig. 297. A double plug,

inserted in the jacks, and connected to a test set, enables either section of the line to be tested. The jacks are mounted side by side in double vertical rows in place of the arrester strips. The jacks are mounted at ½-inch centres.

Through Junction Lines.—Similar test - jacks are also

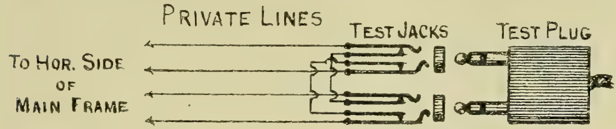


Fig. 297

fitted for certain junctions lines between two exchanges situated in opposite directions, which are merely brought into this exchange for convenient testing and the localising of faults.

Order Wires.—Test-jacks are also used with the outgoing order wires, but these are in addition connected up to the

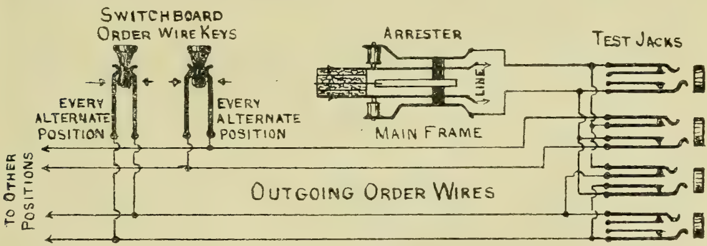


Fig. 298

arresters, as shown in Fig. 298, and have four jacks, which enable them to be tested in various ways.

The *horizontal side,* H S, of the intermediate frame has 15 rows or shelves, each of 36 20-line sections, thus providing for, $36 \times 20 = 720$ lines. The total capacity is $720 \times 15 = 10{,}800$ lines.

The *vertical side,* V S, is made up of 37 upright bars, each accommodating 300 lines, the whole giving room for $300 \times 37 = 11{,}100$ lines. This is shown on the left of Fig. 295.

Part of the latter frame is utilised for the fitting of tabs for the connection of register meters, so that they may be cross-connected on to the subscribers who pay on the message-rate system.

Relay Racks.—The two *relay racks* are about the same length as the intermediate frame (20 feet), the nearest one being set so as to leave a passage of about $2\frac{1}{2}$ feet between the vertical side of the latter frame, and the second one so as to leave a passage of 2 feet between the two racks—all the wiring being done in this passage. These are shown on the right of Fig. 295.

There are 12 bays in each rack, and each bay accommodates 30 strips of 10, or 300 relays, thus giving a total capacity of $300 \times 24 = 7200$ pairs of relays in the two racks.

Subscribers' Service Meter Rack.—This, shown at the bottom of Fig. 296, is an upright skeleton frame, on which the meters are fitted in strips of 20, which are $33\frac{3}{4}$ inches long and $1\frac{1}{4}$ inches wide. The frame is about 9 feet high and 6 feet wide, divided into 2 bays, each of which can accommodate 60 strips of 20, or 1200 meters.

The meters used are simply mechanical counters somewhat similar to Veeder cyclometers. Each is actuated by an electro-magnet, to the armature of which is attached a lever, which, when operated, moves the pawl of a ratchet wheel, and moves on the train of wheels. Figs. 299 and 300 show two views of the meter. In order to obtain a long movement, the end of the magnet core is rounded, and projects through a hole in the armature.

The subscribers' meter rack is seen in the distance on the extreme right of Fig. 295.

Operators' Service Meter Rack.—This is similar to that above described, but each of the 2 bays has a capacity for only 200 meters. The same kind of meter is used. This rack is often accommodated in the switch-room (as at Barnsbury), so that it may be convenient for the switch-room managers or others to note the readings.

Line Resistance-Lamp Rack.—This rack supports the resistance lamps, which are fitted in the B wire circuit of each line,

in order to prevent an earthed or otherwise faulty line from short-circuiting the battery, and also to show the condition of the lines in regard to leakage, etc.* The lamps are mounted on brass frames, $9\frac{1}{4}$ inches high by $5\frac{1}{4}$ inches wide, which will accommodate 101 lamps. The odd lamp is fitted at the top of each set. Each of such odd lamps is connected to a press button mounted on a separate base, on pressing which the lamp is connected direct to the battery, and its brightness serves for comparison with that of other lamps, caused by excessive leakage, etc., so that the resistance, etc., in circuit may be judged.

Each block of lamps is connected to an operator's position, but only as many lamps are fitted as there are subscribers' lines attended to by such operator; thus in the Barnsbury exchange only 81 lamps were fitted at the time of writing, but these may be increased to 101 later on, when more lines are taken per operator.

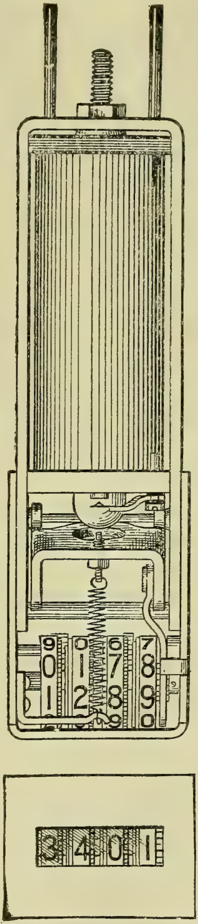


Fig. 299.—Full size

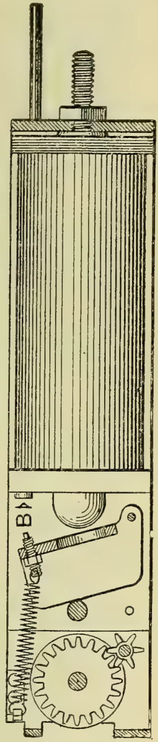


Fig. 300

* These line resistance lamps have not been fitted in the latest exchanges, as they have been found to be unnecessary.

Provision is made at Barnsbury for the mounting of 86 blocks of lamps in 5 bays, the whole being enclosed in a non-flammable cabinet fitted with glass doors, as shown on the left of the photographic view, Fig. 301. This figure also shows one end of the horizontal side of the I.D.F., in the centre of the view.

Repeater Rack.—This is a frame for carrying the repeating coils used in conjunction with each pair of connecting cords on the switch-boards. It is made up of two angle-iron vertical frames, fitted 10 inches apart, so that the ends of the wooden bases on which the repeaters are fitted rest on ledges on the two frames, and the soldering tabs are convenient for fitting. The length of the frame is $15\frac{1}{2}$ feet, and there are 29 shelves in the height, each with a capacity for 54 repeaters, or a total of 1566, sufficient for $\frac{1566}{17} = 92$ operators' positions. This rack is seen on the left of Fig. 302, in a line with the fuse panel. Part of the vertical side of the main frame is shown behind on the right.

Repeaters or Translators.—These, as mentioned in Chapter I., are induction coils having, usually, their separate coils of about the same resistance, number of turns, etc. A number of different forms are employed, and they may have 2, 3, 4 or even 8 separate coils wound on the same core, which is usually of fine iron wires. The most efficient repeaters are provided with a complete iron covering as well as core, to give a complete magnetic circuit and confine the lines of force so as to prevent inductive action between neighbouring repeaters. Repeaters were formerly most generally used for the purpose of inductively connecting single wire lines to metallic circuit trunk lines, as shown in Fig. 303, so that the benefit of the latter lines, as regards freedom from inductive noises, etc., would not be lost on connecting the earthed single lines. Their use now, however, is more particularly in connection with common-battery exchange working, to enable the battery current to be fed independently to two sub-stations put in connection, and for other purposes.

Fig. 304 is a sectional view of one of the most common

forms of repeater. There are eight windings, four at each

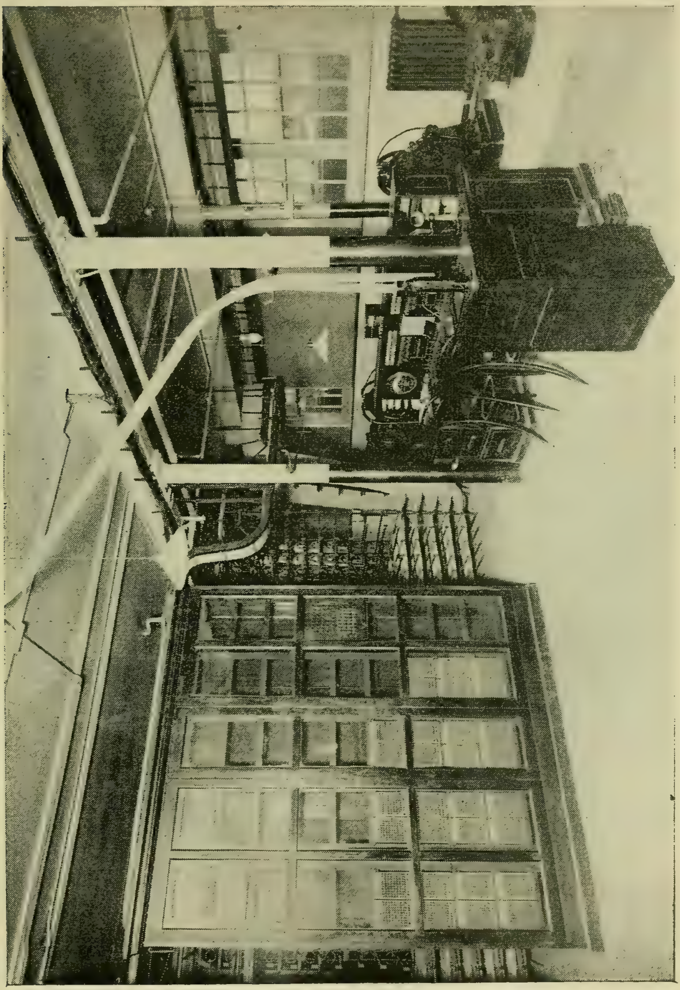


Fig. 301.—Resistance Lamp Rack and Wire Chief's Desk

end, separated by an insulating fibre washer, as shown. The

outside windings at each end are connected to the inside windings to form one coil, and the two intermediate windings to form another, so that all the four coils may be of an

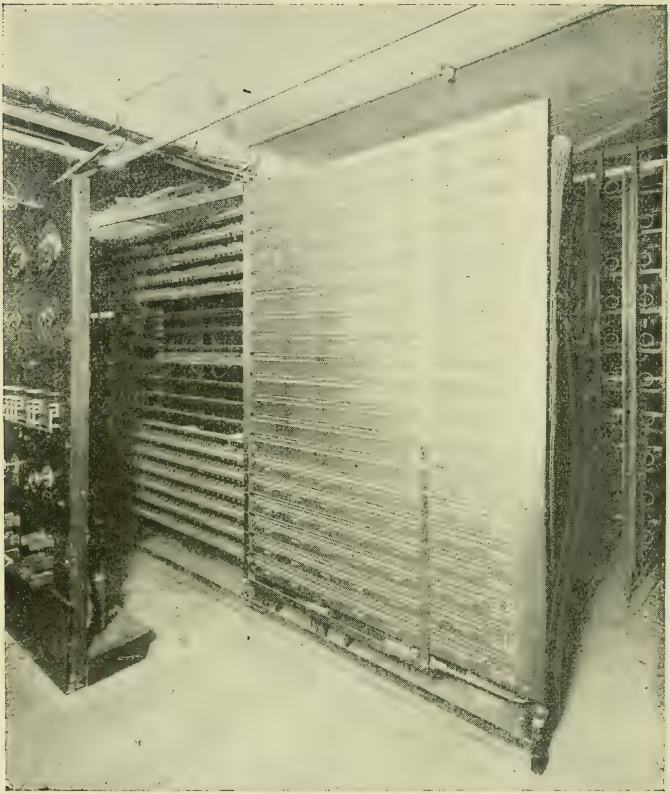


Fig. 302.—Repeater Rack and Fuse Panel

equal resistance and inductance. The outer case is a soft-iron tube with iron end pieces. Two fibre plugs are driven in the ends so as to compress the thin iron core wires firmly against the iron end pieces.

What are known as the No. 11A and No. 11B repeaters are built up in a similar manner to the above, the two types named differing only in the manner in which the soldering tab terminals are mounted on the base-board. The latter is 2 inches wide by 10¾ inches long. In the 11A the six ter-

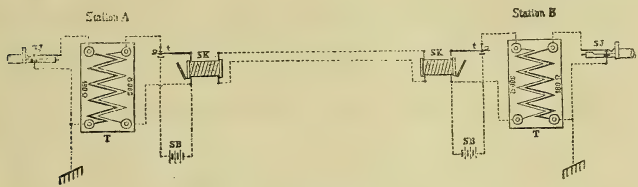


Fig. 303

minals are mounted four at one end and two at the other, as shown in Fig. 305, which shows the coils as though wound on two separate cores. On the 11B the terminals are all mounted at one end, so that the repeaters can be fitted on a wall rack where only one side can be reached. Each of the four coils in these repeaters has a resistance of 42 ohms.

A newer and rather more efficient form of repeater is known as the "toroidal." This is a ring form of repeater, which has been referred to in Chapter XVI., Fig. 239. It

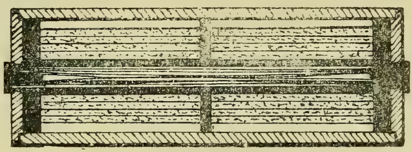


Fig. 304

is covered with a circular iron casing, and two repeaters are mounted on a base-board 4 inches by 10¾, so that they occupy exactly the same rack space as two No. 11 repeaters. The resistance of each coil is only 22½ ohms in this type. The connections are similar to those of Fig 305.

Condenser Rack.—This frame is for the accommodation of the 2½-microfarad condensers used in connection with the incoming junction lines. It is 6 feet wide, and has a capacity for 1080 condensers.

U

These condensers are each contained in tinned iron cases, which are $7\frac{1}{2}$ inches long, $4\frac{11}{16}$th inches wide and $\frac{11}{16}$ths of an inch thick. The terminal tabs are fitted on a strip of ebonite screwed to an end lid. The condensers should withstand a voltage of 200 and have an insulation resistance of at least 150 megohms.

The condensers are laid on their longest edges on the shelves, so that the ends with the terminal tabs all come to one side. The frame is 7 feet $3\frac{1}{2}$ inches wide and 7 feet 10 inches high. It is divided into 2 panels, each of which has 10 shelves, each

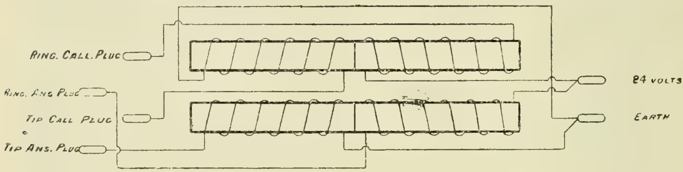


Fig. 305

of these shelves accommodating 54 condensers, or a total of 1080.

In addition to the frames, etc., so far described, the apparatus-room at Barnsbury, also contains the wire chief's desk, shown on the right of Fig. 301, on which is fitted apparatus for the rapid testing of faults, etc. This will be referred to in Chapter XXVIII. It also contains the power equipment, in the shape of electric motors, generators, ringing dynamotors, etc., which will be described in the next chapter.

Two dotted squares in Fig. 296 show the positions of holes through the ceiling for the passage of the cables to the switch-boards, those for the subscribers' sections passing through hole S, and those for the junction-boards passing through hole J.

CHAPTER XXII

THE POWER PLANT

IN modern telephone exchanges a considerable output of current is required to operate the numerous and varied pieces of apparatus at the central office, and to supply the sub-station instruments, so that the method of producing and regulating this current becomes a matter of much importance. In some large C.B. exchanges as much as 400 amperes of current are required during busy times, so that the apparatus employed in such an exchange must be of almost as large and substantial a nature as that for the electric supply of a small town.

Supply.—The primary source of supply of the current is determined by local circumstances, but it is now generally possible to take advantage of the electric supply which exists in nearly all towns. Such current cannot, however, be used directly for working the instruments, as, among other reasons, it is of too high a voltage and too unsteady a character, and would give rise to humming noises in the instruments. For the same reasons machine-generated currents are not at present satisfactory, although it has lately been found possible to use dynamo currents to directly supplement the storage-battery currents, and even to operate alone in emergencies. Such direct use of dynamos for generating working currents without giving rise to disturbances on the lines is, in fact, now specified.

For small installations, primary batteries such as the "Gordon," have proved convenient; but for large installations storage cells of large capacity, and with special means of charging, have proved much the most convenient and adaptable.

The best pressure for the general working current has been found by experience to be 24 volts, so that, as the voltage of a storage cell varies between 1·8 and 2·5 volts, or a mean of about 2·2, a set of eleven cells in series is required to give the 24 volts.

Until recently it was found necessary to provide two batteries of eleven cells, so that one set could be recharging while the other was discharging. It was not then feasible to take working current from the battery when the latter was connected to a machine generator for charging. This, however, is now found possible, by running the dynamo at a high speed, and building it with a large number of sections in the armature coils and commutator, so that but one set of cells is now provided, and at the busiest hours the generator is also connected on to the mains at the same time. When so connected, the storage cells appear to moderate the humming noises by absorbing the waves. If necessary, choking or high inductance coils are included in the dynamo circuit to further reduce the humming.

Dynamo Generators.—Some form of dynamo machine is nearly always used for charging the storage cells. Such machines are a development of the magneto-generator described in Chapter VI., although, strictly speaking, that also is a "dynamo," as it is "a machine for converting mechanical energy into electrical energy"; the term, however, is now generally restricted to such a machine not having permanent magnets. The Siemens' armature of the magneto-generator is developed into what is called the "drum" armature by winding a number of coils of wire over the outside of a hollow iron cylinder (built up in sections); these coils are wound across a large number of diameters instead of only in one direction, as with the magneto-generator armature. Fig. 306 shows how such a drum armature, wound with four coils, is, connected, and by tracing the arrow-heads it will be found that they are joined up so as to form a continuous coil. In order to get a direct current in one direction, it is necessary that each of the coils of the armature be joined in a proper

manner to one of a series of insulated metal strips, arranged longitudinally, so as to form a cylinder. Metal or carbon "brushes" for collecting the current are arranged to bear on the strips at opposite sides, so as to form the "commutator." Without such an arrangement alternating currents would be delivered from the machine. The figure shows how the connections are made. The arrows show how the coils are connected, and do not represent the direction of the currents through them.

In place of permanent field-magnets, electro-magnets are

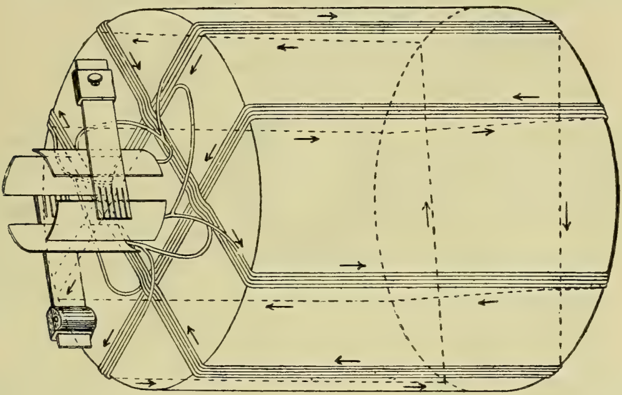


Fig. 306

employed, these being energised by the generated current itself. It is found possible to start the current in such machines without the help of outside current, owing to the fact that a certain amount of residual magnetism is always found in the iron cores of electro-magnets. This starts a weak current when the armature is turned, and this current becomes intensified as the speed is increased by reaction between the armature and field-magnets.

The armature may be of another form, called the "ring" armature, in which a thick ring made up of a coil of thin soft-iron wire forms the core. On this a continuous coil of copper

wire is wound, in the manner shown in Fig. 307. This figure also shows how connections are made from the coil, or series of coils, to the plates of a commutator and the collecting brushes + and −, from which the current is collected, the arrow heads showing the direction of the current.

The figure shows each single turn connected to a commutator plate but there may be a number of turns of thinner

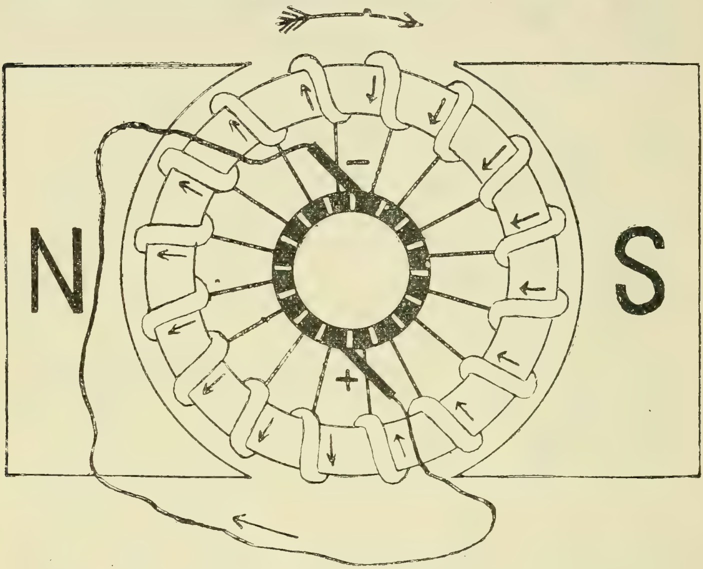


Fig. 307

wire between each connection. The greater the number of coils into which the armature is divided and the greater the number of commutator plates, the steadier will be the current derived from it if the driving speed is kept constant. In the generator most generally used for telephone work the number of armature windings and commutator plates is 175.

Dynamos are called "series" or "shunt" machines according to whether the field-magnet coils are joined up in series or in shunt with the armature. Shunt machines are

generally used in telephony, as giving a steadier current, and one in which the voltage can be more readily adjusted. The

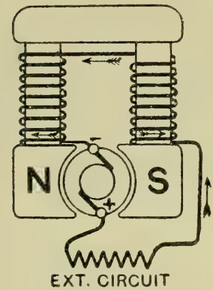


Fig. 308

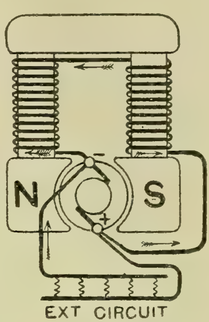


Fig. 309

magnet coils of shunt machines are generally wound to a much higher resistance than the armature. In "compound" dynamos a combination of both series and shunt windings is used.

Figs. 308, 309 and 310 show how the field-magnet coils are connected in a series, a shunt, and a compound direct current dynamo respectively.

Motors.—Dynamo machines are generally reversible, so that if current is sent through the machine from some outside source, and the brushes are in the proper position, the armature will be subjected to a "torque"—that is, a force tending to drive it round. The machine then becomes a "motor," and can be used for driving other machines. Thus motors are of similar construction to dynamos.

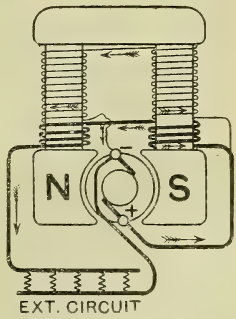


Fig. 310

Motor Generators.—For obtaining the battery-charging current the method most frequently adopted when an out-

side source of current supply is available is to use the latter to drive a motor properly designed for the particular current supply, and to employ this motor to again drive a dynamo, also properly designed, to give out the current at the voltage required for charging the cells, which is usually about 30 volts.

The general method of driving is to couple both motor and dynamo on the same base plate, so that the two machines work as a single one, forming a "*motor generator.*" Fig. 311 shows one of these as made by the Western Electric Co. Drum armatures are used, and the field-magnets have four poles attached to thick cast-iron rings, which form the outer casings. The speed is arranged between 1100 to 1200 revolutions per minute, the generator giving a voltage of between 22 and 37, and amperage of from 20 to 800, depending upon the size of the machine. The voltage is regulated by means of a "rheostat," which is an arrangement for inserting more or less outside resistance in the circuit of the machine. The number of armature windings and commutator plates or segments is 175.

In order to be prepared for breakdowns in the machines or current supply, it is generally necessary to provide a duplicate generator, driven by some alternative source of power, such as another motor driven by a second and independent current supply, or by a gas-engine. The gas-engine is usually adopted when there is no current supply available.

Alternating Current Motors.—In many cases the outside current supply is of an alternating nature, and it is then necessary to provide an alternating-current motor, or in some manner to "rectify" the current from alternating to continuous, if advantage is to be taken of the supply.

Until recently, such motors could only be driven at some one speed, which depended upon the frequency of the alternations, and independent means of starting and accelerating up to that speed had to be provided, such as a small direct-current motor, coupled to the alternating one, and driven by current from a battery. This difficulty has, however, now been removed by the introduction of *Induction Motors.* These are

motors in which the rotation is due to the reaction of the

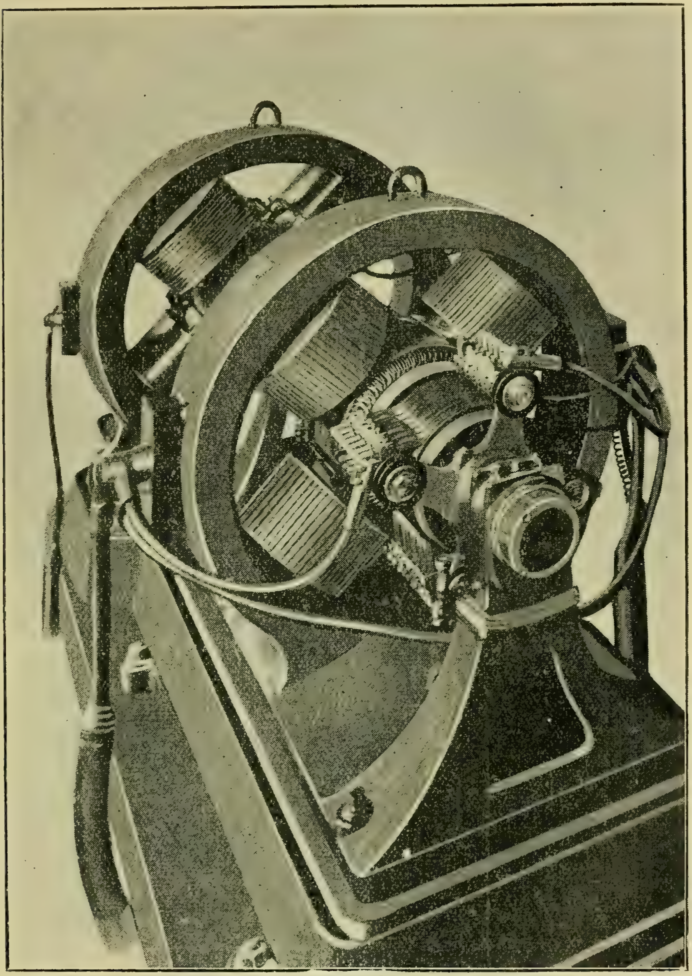


Fig. 311

working currents and currents which circulate in the armature

or "rotor" coils, which latter currents are wholly due to the inductive action of the magnetic field of the field magnets, or "stator." The rotor coils are complete in themselves,

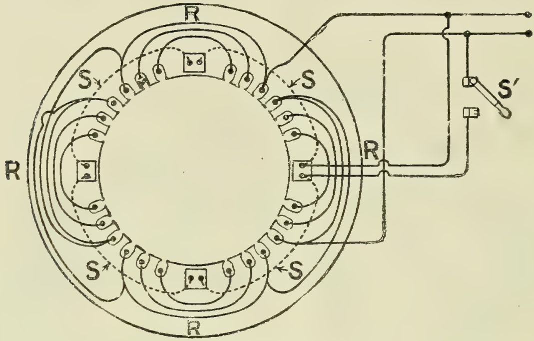


Fig. 312

and except for starting purposes would not need to be extended from the rotor itself. By a special "starting" winding of the field magnets, and a special connection of the armature coils, these machines are made self-starting, even when a load is left on the machine.

The Heyland Motor.—This is the form of induction motor

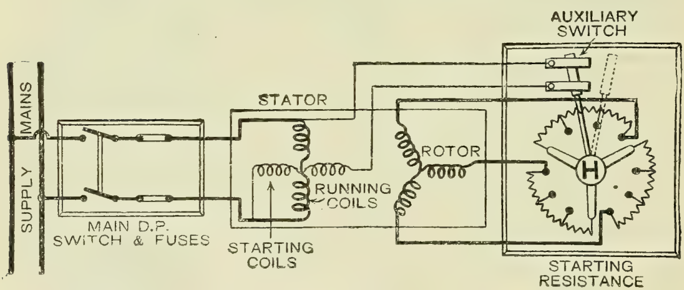


Fig. 313

generally used for telephonic purposes. Fig. 312 gives the connections of the stator windings, the "running" coils being shown at RR, the "starting" windings SS in dotted lines,

and the starting switch at s′. Fig. 313 shows the full connec-

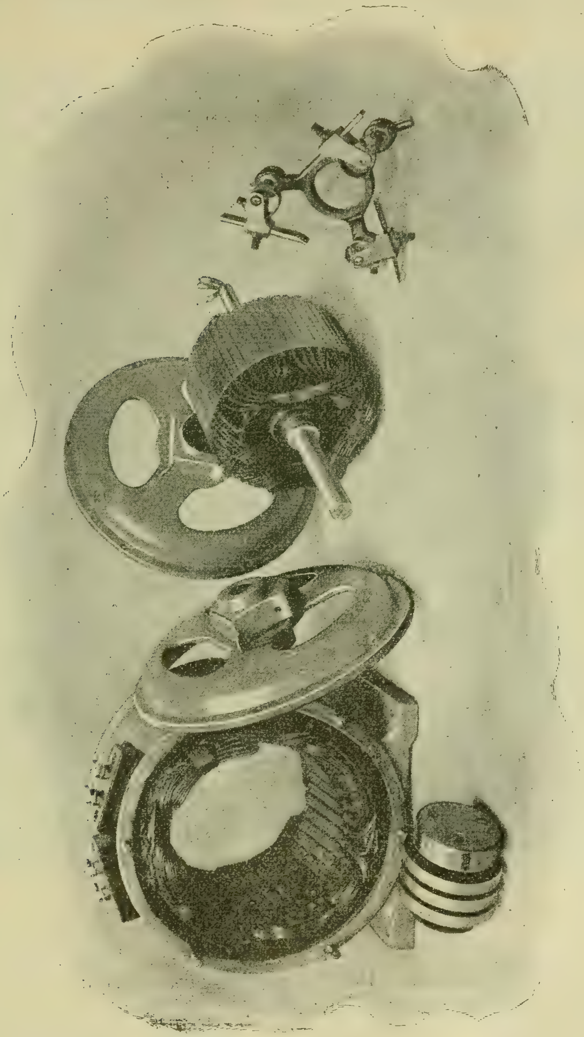


Fig. 314

tions of the motor with rotor and starting resistances, etc.

The starting windings of the stator produce magnetic poles which are intermediate in position between those produced

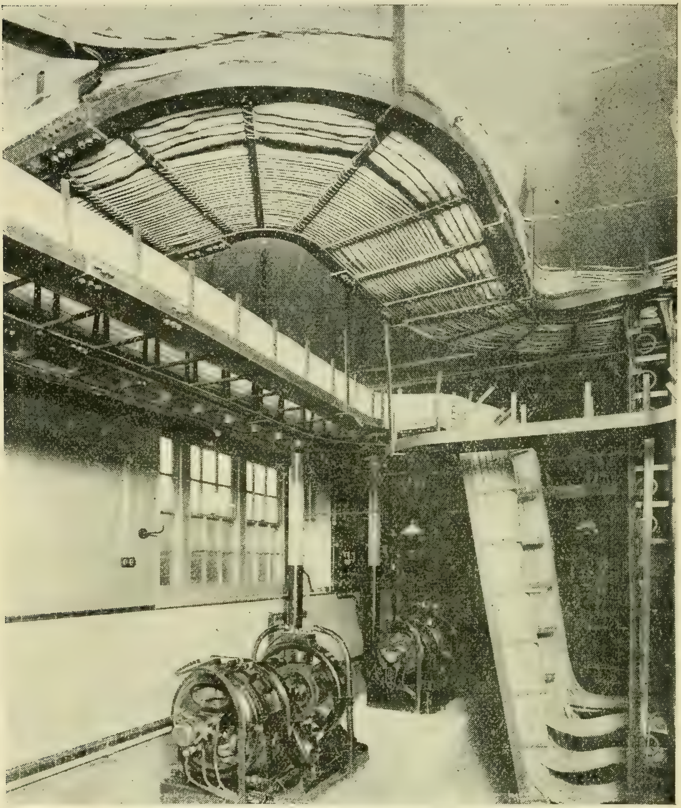


Fig. 315.—Barnsbury (London) Apparatus-Room

by the running coils, the latter being four in number situated on vertical and horizontal diameters.

Fig. 314 gives a view of the various parts of the motor taken to pieces. These figures are taken from Mr Perrin-Maycock's

"Electric Lighting and Power Distribution," to which excellent book the reader is referred for further information.

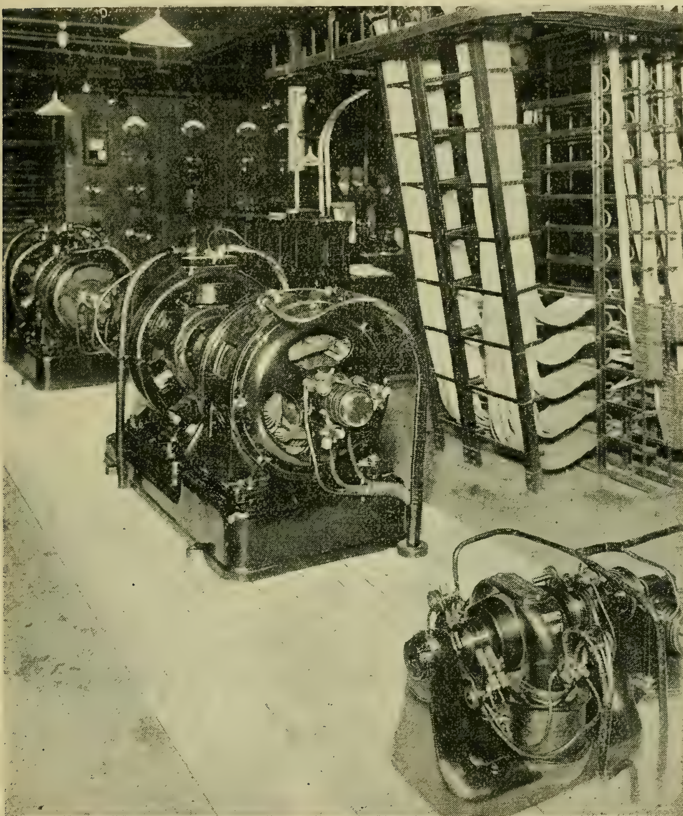


Fig. 316.—Ringing Dynamotor, etc. (Barnsbury), London

Figs 315 and 316 show two 12-H.P. Heyland motors, connected to generators, as fitted in the power-room of the "Barnsbury" exchange.

Ringing Plant.—In addition to the apparatus already

described, separate alternating-current generators are provided for producing the current used for ringing the sub-station bells and also for giving the "tone" tests for "engaged" (called the "busy back" tone), "don't answer," lamp flashing, junction-line ringing, etc.

Dynamotor.—The machine mostly used for the above purpose is a motor and generator combined in one machine; the same field magnets serving for both and the armature having two separate windings, connected to separate commutators mounted on opposite ends of the shaft. Carbon brushes are used for the commutators, as these work with less sparking and cause less trouble from short-circuiting than the ordinary copper brushes. Such a "dynamotor" is shown at the right-hand bottom corner of Fig. 316. On an extension of the shaft of the machine a *slip-ring* and an *interrupter drum* are fitted, the latter being subdivided into brass and insulating parts, so as to produce interruptions of about 200 times per second (with normal speed of machine), in currents passing through circuits of which they form part. The machine is generally arranged to run at the rate of 1000 revolutions per minute and generate ringing current at a pressure of 75 volts and 1000 alternations per minute.

On the end of the shaft a screw is fitted, which gears into a toothed wheel with 100 teeth, fixed in the centre of a wide drum which revolves on a spindle fixed at right angles to the dynamotor shaft. This drum, shown on the extreme right of Fig 316, revolves once in six seconds, and is fitted with a number of slip and interrupter rings, the latter of which are arranged to give various distinctive interruptions such as:

1. *Busy-back* and *Don't Answer*; on which contact is made every half second and also a break for another half second.

2. *Lamp Flashing*; to make for 0·6 and break for 0·9 second so as to complete four interruptions in six seconds.

3. *Interrupted Ringing*; contact for three and break for three seconds.

Pulsating currents, both positive and negative, are now also provided for party-line ringing.

The interrupted ringing current is found to be more effective for calling than the continuous, and current is economised.

Two ringing machines are usually provided, one, a small

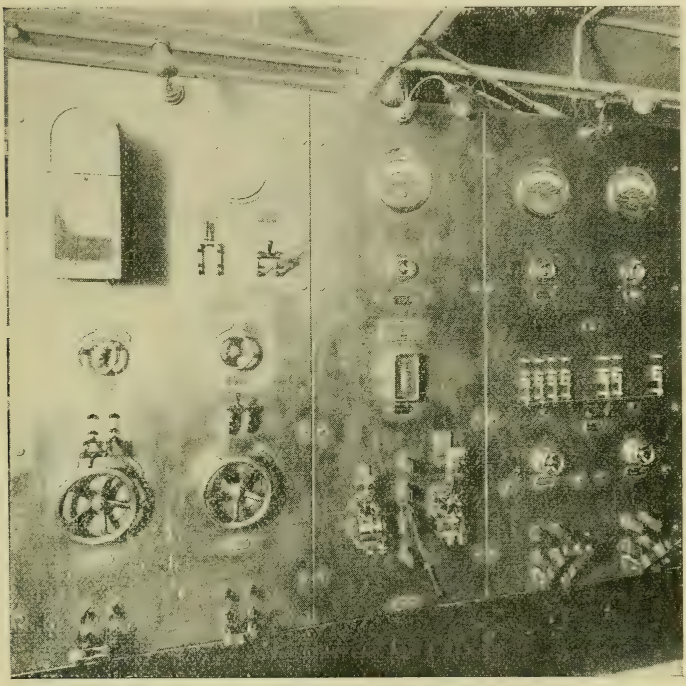


Fig. 317.—Power Switch-Board

motor generator, being arranged to be driven by current from the storage battery.

The connections of these machines are shown in the left-hand top corner of Fig. 318.

Auxiliary Apparatus.—A number of instruments are required in connection with the batteries, generators, and motors, for the purpose of observation, measurement, safety, etc., and

these are fitted on thick slabs of slate, which form the panels of the "*power switch-board.*" The standard arrangement of the instruments on this so-called "board" is shown in Fig. 317, and Fig. 318 shows the most usual connections of the various instruments, etc., for central-battery working.

The most important pieces of apparatus are as follows :—

Main Switches.—Starting with the current supply, a large "double-bar" or "double-pole" switch, with a well-insulated handle, is used to connect the motor to the supply mains when needed. All such switches in the principal circuits, must be of a very substantial nature, as they have to carry heavy currents. They are made of a large body of copper, so that a firm and large surface contact is made, and are so arranged that when this contact is broken a long gap is instantly introduced between the contact points, in order to prevent the formation of an electric arc across the gap, as arcing is possible if the gap is small or made slowly.

Starting Resistance.—When an E.M.F. is connected to an electric motor at rest, the strength of the current passing through the coils is according to Ohm's law, but when the motor is in motion the current is not according to this law (or rather appears not to be so), as the faster the armature revolves the less is the current in the armature coils. This is owing to the fact that the revolutions of the coils in the magnetic field create a "back" E.M.F., the voltage of which is in proportion to the speed, and which opposes the original or "impressed" E.M.F. As the full current at starting, if put on suddenly, may be likely to damage the coils by heat, and also put a great mechanical strain upon them, a "starting switch" is used. This, by inserting a resistance in series with the machine, and then gradually cutting it out as the motor gets up speed, gives a gradual increase of E.M.F., and therefore current, to the coils.

Generator-Field Rheostat.—The generators used are usually "shunt" wound machines, and a rheostat is included in the field-magnet circuit, so that by inserting more or less outside resistance the current through the magnet coils can be varied

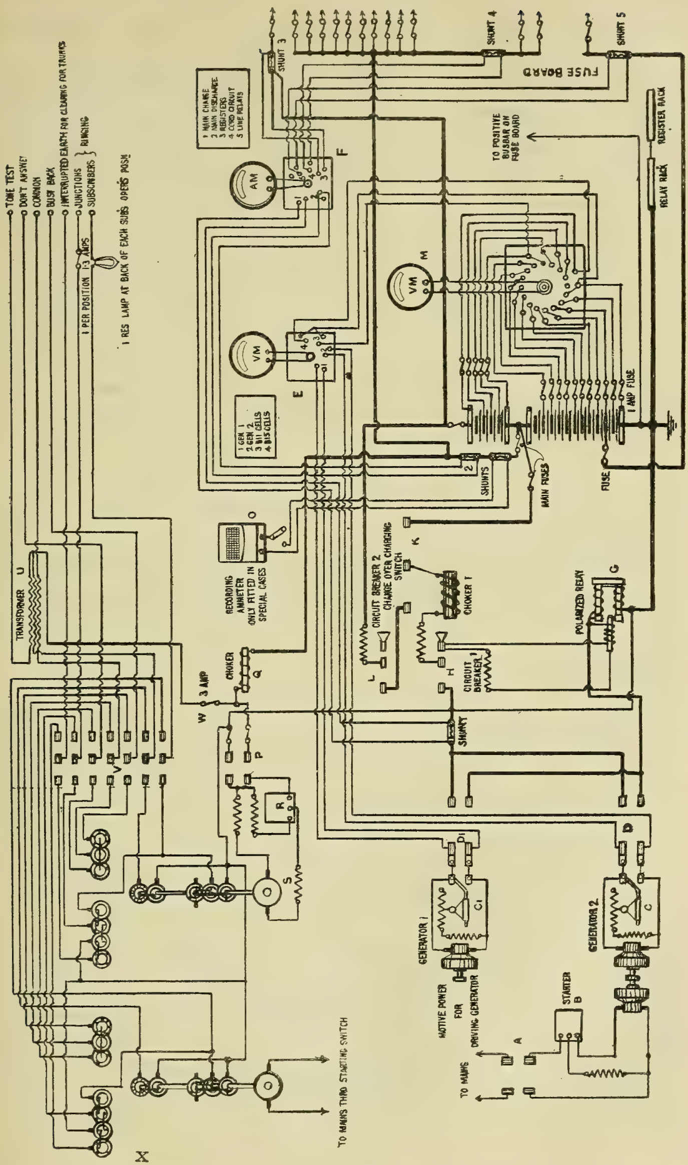


Fig. 318.—Connections of Power Plant

as desired, and the E.M.F. generated in the machine can be raised or lowered at will.

Double-Pole Switches.—These are heavy switches, used to connect the generators to the battery when the machine has attained the proper speed for charging—viz. so as to give an E.M.F. of about 30 volts. If connected before the voltage was equal to that of the battery a reverse current would be sent through the machine and the polarity of the field-magnets reversed. To guard against such an event, and also against an excess of current due to some accidental short-circuit, a *Circuit Breaker* is inserted in the main circuit. This is a spring-lever switch held by a catch, which is released either by a very low-resistance electro-magnet in the main circuit operating when the current reaches a certain excess point, or by a comparatively high-resistance electro-magnet energised by means of current connected by a polarised relay in the main battery circuit, which only operates when the current is reversed.

Change-Over Switch.—This comes next in order, and is a heavy switch, having a pivoted bar, which can be connected to either one of two contact-pieces, one of which is joined to the main 11-cell battery, used for nearly all the work of the exchange, and the other connects to an extra set of four smaller cells, used to add an extra E.M.F., so as to get a total of about 32 volts for working the message register armatures.

Measuring Instruments.—For the measurements of the electrical pressure and strengths of the currents in the various circuits two voltmeters and one ammeter are fixed at the top of the switch-board, each furnished with double-bar switches, by means of which they can be connected into the various circuits.

One voltmeter is used exclusively in connection with the battery. It is furnished with a switch, by means of which it can be connected to each individual cell. Its readings run from 0 to 3 volts.

The other voltmeter is arranged to read from 0 to 50 volts, and has a switch, by means of which it can be connected to the

terminals of the 11-cell main battery or to the whole 15 cells, also to either of the two generators.

The ammeter has a switch, by means of which it can be connected to (1) the main charging circuit; (2) the main discharge circuit; (3) the service register discharge circuit from the 15-cell battery; (4) the operator's cord circuit supply main; and (5) the line relay supply circuit.

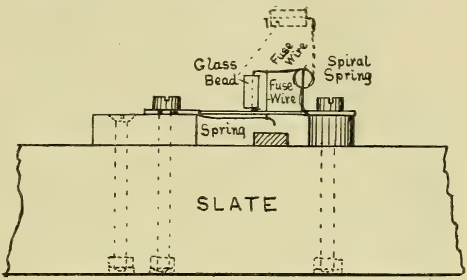


Fig. 319.—Scale $\frac{2}{3}$

The current measured does not all pass through the ammeter, but the latter is connected as a shunt to the ends of a known low resistance, which is included in the main circuit, so that some known proportional part only passes through the ammeter. In some of the largest exchanges these instruments are required to read up to 400 amperes.

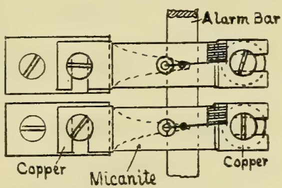


Fig. 320.—Scale $\frac{2}{3}$

Recording Ammeter. — In the more important exchanges a recording ammeter is sometimes connected to the main discharge circuit, and automatically registers a curve, which shows at a glance the amount of current which has been used at any time of the day. This curve, being proportional to the number of calls and connections (if the lines are in good order), acts as a check on the record of calls taken directly on certain days. See Fig. 323.

Fuse Board or Panel.—On this are fitted the alarm safety fuses for the various leads which carry current from the battery. They are mounted on slate panels held in iron frames.

Fig. 319 shows a section of one of the alarm fuse holders in position on a slate base, and Fig. 320 gives a plan of two of them. A strip of micanite (which is an insulating substance composed of mica and shellac), $1\frac{5}{8}$ inches long and $\frac{3}{8}$ths wide, is bound at its two ends by thin copper, a strip at one end being turned up, and carrying a spiral wire spring, on a bent end of which a white glass bead is threaded. At the other end, which is clamped to the battery bus bar, a flat German silver spring is carried. The fuse wire is soldered between the flat and wire springs, which pull on it in opposite directions. When the fuse melts, the flat spring moves into contact with the alarm bar, and causes the lighting of a lamp, and the ringing of a bell which is connected to one end of the bar, thus calling attention to the trouble, and indicating the strip affected. The wire spring takes the position shown by the dotted lines in Fig. 319, and the white bead thus serves to indicate the particular fuse affected.

In order to prevent the wrong size of fuse being used, the bases of the various sizes are made to differ in length, so that they will fit only on the proper holders.

The fuse panel is fixed near to, or forms part of, the repeater coil rack, as the repeaters are joined directly to the battery. It should also be fitted near to the power switchboard, in order that the main wires may be short.

A fuse panel is shown on the right of Fig. 302.

CHAPTER XXIII

TRAFFIC STATISTICS

For many years it has been the practice to register the number of calls taken by each operator in an exchange on some particular day in each month, but this was done more as a matter of curiosity, or for advertising purposes, than for any definite value of the figures obtained in connection with the exchange itself. Recently, however, the records have become of much more consequence and interest, as they are used as a basis for calculating the work to be assigned to the operators, for the redistribution of the subscribers' lines, the size and number of positions of projected switch-boards, and generally as a guide as to the arrangements necessary to give the greatest operating efficiency and economy in an exchange.

As such records have thus become of great importance in the design of switch-boards, the duty of dealing with the statistics, which was formerly associated with the commercial side of the business, has now become of much value to the engineering branch. As so much depends on their accuracy, much more care is necessary to ensure that the figures obtained may be depended upon, so that new methods of registering and checking, which are almost automatic, have been adopted in the larger exchanges in place of the pencil and paper, or the "peg-count," records formerly in use.

Peg-Count. — The "peg-board" is merely a kind of enlarged cribbage board. One hundred holes are drilled in it in 10 horizontal rows of 10 each, these being used for the counting of the individual calls as received by moving a white peg along from hole to hole. Another row of the holes in the top right-hand side are for noting the separate hundreds, a

black or other coloured peg being often used for this. Two holes at the top left-hand side are for the pegs when not in use. It is, however, much more usual to employ rows of 20 or blocks of 100 spare jacks, in front of each operator's position, in place of the special peg-boards.

The general practice in making the count is to choose a certain day in each month, taking special care that there is nothing abnormal about the day chosen, so that the result may represent a fair average. The record is taken either from midnight to midnight, or for 12 hours, from 8 A.M. to 8 P.M. At the end of each hour or half-hour the calls made at each position are noted, the best method of doing this being to provide a duplicate peg-board (when such are used) for each position, and for the supervisor to change them at the end of each hour; or duplicate pegs may be used, and the first pegs left in position on the sounding of a gong at the end of the hour.

Checking.—As the counts made by pegs or otherwise cannot be altogether depended upon, it is necessary that the supervisors should give special attention to the checking of the records by actual observation of the operators and otherwise. A good plan for this is to count the number of pairs of plugs and cords in use on the different operators' positions, say, every five minutes during an hour. The average number in use multiplied by some constant number which has been previously determined by actual observation, will be found to give a near approximation to the truth, and may be compared with the figures recorded by the operators. It will also be found that there is a nearly constant ratio in any one exchange between the number of calls per busiest hour and the total number of calls per day. This ratio, however, differs for different exchanges and different classes of exchanges, being largest in residential districts, where the calls are pretty evenly distributed during the hours of the day.

In exchanges where the calls are recorded by register (as described in Chapter XVII.), the records are taken each hour from the operators' registers, which are often fitted in the

switch-room for convenience of reading, but sho ld be kept from the operators' view. As with gas meters, it is necessary to subtract the meter reading at the previous hour to get the calls during the last hour. The hourly or half-hourly records are tabulated on special forms, on which are also shown the number of lines joined to the centre, he number of stations, etc. The lines are divided into different classes, such as flat-rate, measured-rate, message-rate, call-office, etc.

Similar records are made for each of the exchanges in a town or district, from which record curves are plotted on squared paper. Careful consideration of such curves will indicate whether the operating is being done economically and efficiently, and in what direction lterations are required.

Operators' Loads.—It is important to note that operators are found to give the best service when they are given a fair load, and are neither over nor under loaded ; in the latter case they are not so alert, and with overloads they get harassed and confused. As a basis for calculation, etc., it is considered that, on a modern C.B. switch-board, an " A " operator should be capable of answering and completing about 200 to 240 calls per busy hour from " flat-rate" subscribers, junction connections being excluded. Junction or " B " operators should be able to handle over an order-wire position up to about 480 calls per busy hour, when machine ringing is provided. In non-C.B. exchanges the figures should be about 200 and 400 respectively.*

Traffic Curves.—The full-line curve in Fig. 321 is one which has been plotted from a 12-hour record of calls taken half-hourly at one of the large provincial centres of the National Telephone Co., having a total of 3103 subscribers' lines. This shows the characteristic features of such curves—such as the two peaks which are generally met with, one before noon (generally about 10.30 or 11) and the other in the afternoon (usually between 3.0 and 4.30) with a deep depression between, at the times when subscribers take their lunch interval.

Operators' Position Curve.—The dotted line curve in Fig.

* 200 calls per busy hour may be taken as an average on a ringing-junction position.

321 represents the number of operators at work on the switch-board at each half-hour during the day. It will be observed that the full number, 35, is on duty between 10 A.M. and 12 noon, when several leave for lunch. All but one are again on duty from 2.30 to 4 P.M., when they begin to leave for the day. It will be clear that the number of operators on duty at any time should be pretty nearly proportional to the call load at that time. This constitutes a well-considered duty arrangement on the part of the switch-room managers, and it is in the assistance which such records and curves render in enabling proper arrangements to be readily indicated that a great part of their value lies.

The total number of calls made in the 12 hours of the above record was 42,066, giving the average number of calls answered per operator's position $= \frac{42,066}{35} = 1202$. The average number of lines per position $= \frac{3103}{35} = 88{\cdot}7$. The average number of calls per line $= \frac{42,066}{3103} = \frac{1202}{88{\cdot}7} = 13{\cdot}55$. The calls made by subscribers for lines on other exchanges were about 15 per cent. of the whole number of calls. In several of the London exchanges the proportion of such calls rises to as much as 90 per cent., so that junction-line working in London is a most serious matter, and modifies considerably the whole design of the switch-boards, besides increasing very materially the operator's work per subscriber's call.

Another matter of great importance in this connection is the number of calls attended to by an operator during the busiest hour of the day, as it is at such a time that the greatest strain is thrown upon the operators, and the board must be so designed or arranged that at such busiest hour the load must not greatly exceed the fair load as previously given. In the record to which Fig. 321 refers, the number of calls per operator's position in the busiest half-hour ran up to 102·4, or at the rate of 204·8 calls per hour. At the same time the number of incoming junction-line calls per position (average

of 6 positions) during the busiest half-hour was 121·5, or at the rate of 243 per hour.

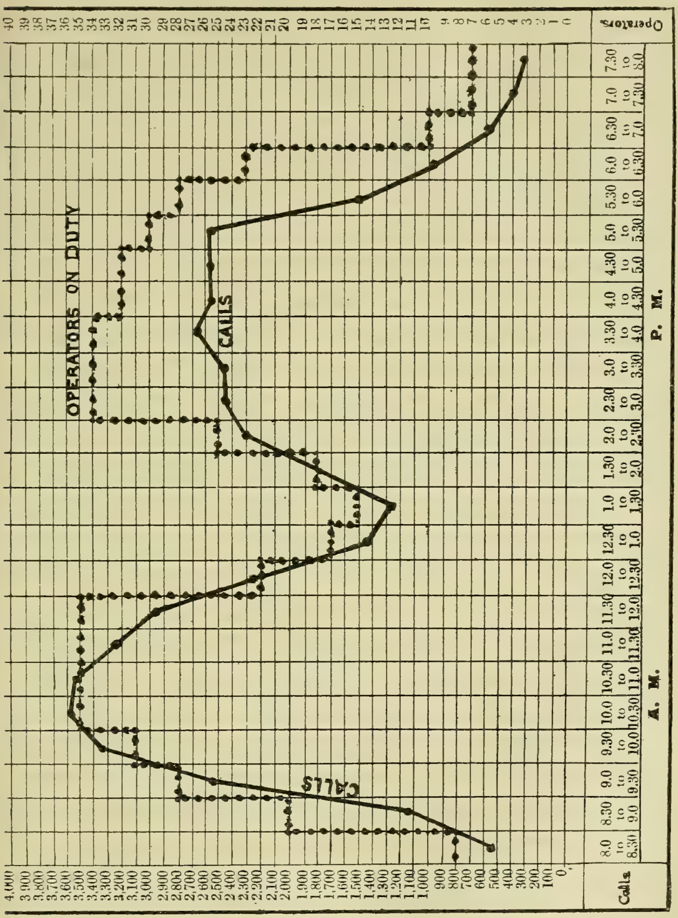


Fig. 321

In counting up the calls allowance is sometimes made for the extra trouble of operating calls necessitating connections through junction lines. Such a call is often counted of a

value equal to 1·5 or 2 calls for a local line, the rate depending on the efficiency of the system on which the junction lines are worked. The more efficient the system the less the value allowed.

Two other similar curves are given in Fig. 322 taken from a small provincial exchange in this country. In this instance it will be observed that the two curves do not agree so well, as it is evident that the hours of duty of the operating staff need alteration both in the morning and afternoon. It will be especially evident that the full operating staff is not in action sufficiently early for service at the time of the heaviest load. The nature of other alterations needed will be readily perceived.

Fig. 323 gives two curves, one made by a recording ammeter and the other plotted from the calls registered on a certain day at the Holborn exchange of the National Telephone Company. This shows how the record of calls can be checked by the record of current used. The two curves do not quite agree, owing to the fact that the curve of calls was made up from figures taken every half-hour during the day, whilst the current curve was made continuously. This figure is taken from an article by Mr B. S. Cohen in the *Electrical Review* for 1905.

Operators' Position Curve.—Fig. 324 is another curve plotted from the records of calls attended to at each of the operators' positions in an exchange. It shows how the load needs distributing by the process of removing busy subscribers' lines from the positions showing a high peak to those which show a low position on the curve. Such changes are, of course, made by means of the intermediate distributing boards, as before described.

In making the necessary redistribution of the lines the average number of calls per operator is found by taking the total calls and dividing by the number of operator's positions. A horizontal line is then drawn through the curve at a height representing this average, and two other lines are drawn, one above and the other below, at values 10 per cent. higher and

10 per cent. lower than the average. An endeavour is then made to so redistribute the lines that the record of calls for

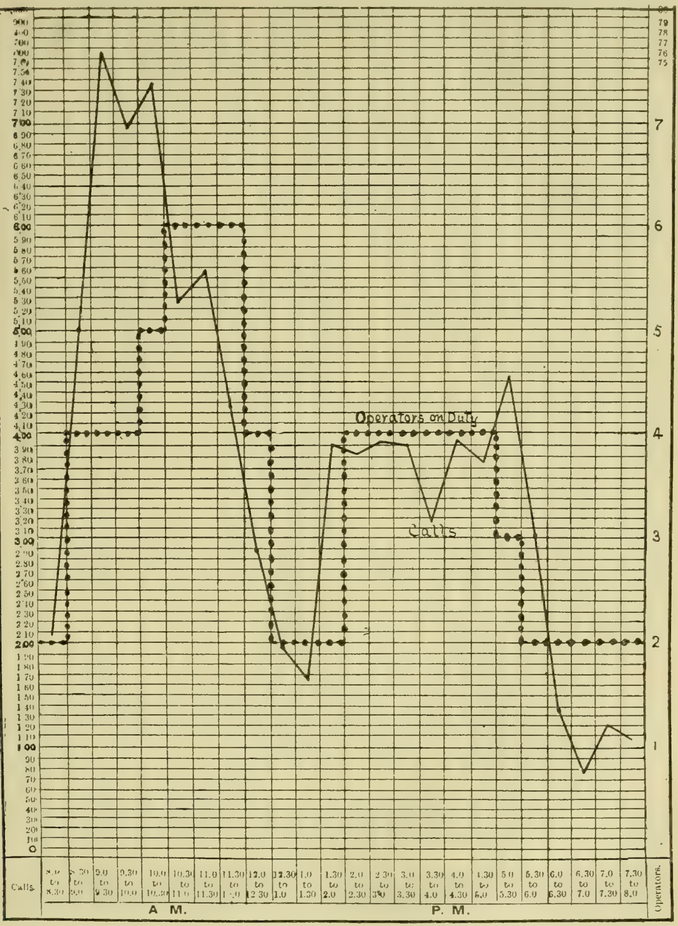


Fig. 322

each position will fall between these two 10 per cent. lines.

Team Work.—The curve in Fig. 324 also indicates that there has been a lack of what is known as "team work." By this term is meant that with such working, operators do not

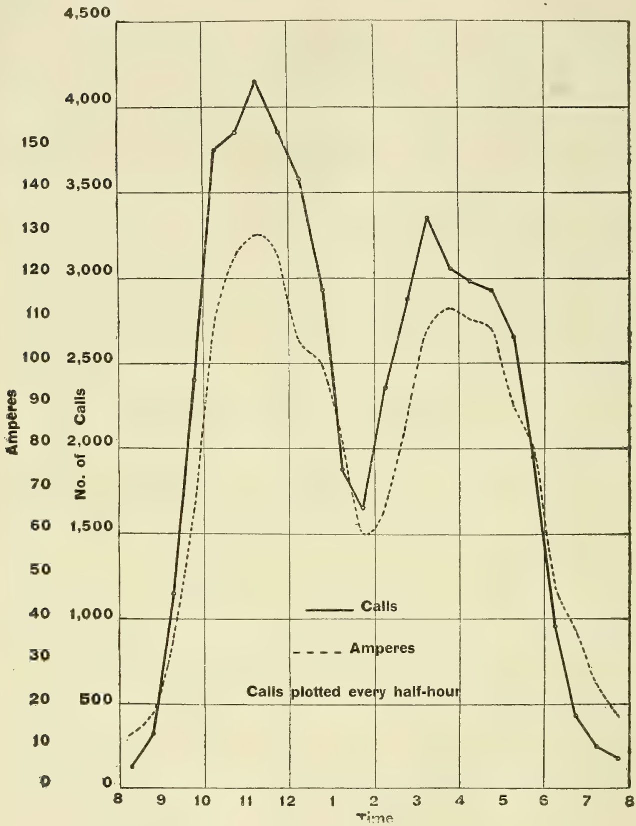


Fig. 323

confine their attention wholly to answering calls on the lines allotted to their position, but also assist at every available opportunity in answering the calls on the positions on each side of them. Such working materially increases the operating

efficiency by equalising the work of the operators, and decreasing the delay in answering calls, so that there is not so much depending upon the distribution of the busy lines.

Switch-Board Design.—In designing the equipment necessary for a switch-board to provide for future traffic in a centre which has already been working for some years (the most

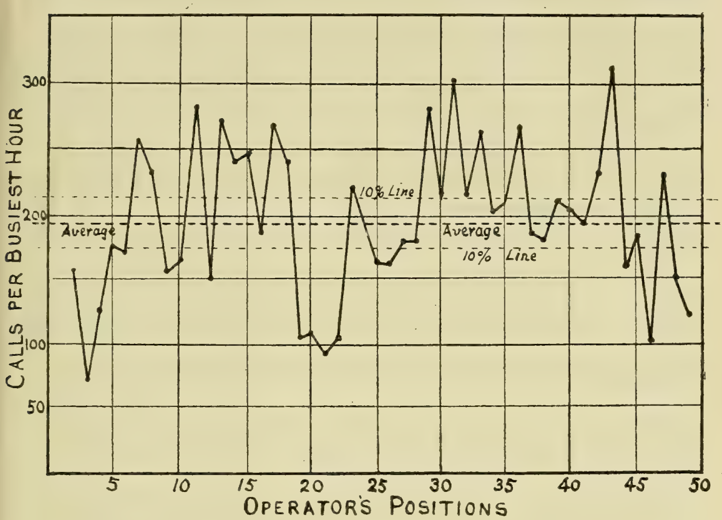


Fig. 324

general case in this country), it is necessary to obtain statistics with regard to several matters, such as :

(1) The rate of growth in the different classes of lines connected.

(2) The variation in the number of calls per line.

(3) The ratio of outgoing junction-line calls to calls for local subscribers' lines.

(4) The number of lines of the different classes per operating position.

The above particulars having been obtained for several years past, curves are plotted from the figures of the monthly

or quarterly records. In order to indicate what will probably be the increase during the next four years, for which the new board is expected to provide, the curves obtained are extended in a regular manner, so as to cover that period on the scale.

Before using figures obtained from the curves as above, it is necessary to make reasonable allowance for anything likely to affect the regular increase of the different items, such, for example, as the adoption of a more rapid and efficient method of operating, which would allow the number of lines per operator to be increased; or the more general adoption of measured-rate working, in which the calls per line are much lower than with flat-rate working.

Having now the number of lines of the various classes for which the new switch-board is to provide, the number of operators' positions on the new board will be determined by dividing the number which represents the probable number of calls to be attended to in the busiest hour by a number which represents the fair call load per operator for the different classes of lines, or such numbers increased by, say, 10 or 15 per cent.

This question of switch-board design is one of great importance, as a large number of different factors require to be carefully considered in all their bearings, and an intelligent anticipation of events in the way of probable alterations in the proportion of the different classes of subscribers is also necessary. In order to ensure and facilitate this careful examination the engineering staff of the National Telephone Co. has in use special forms, on which detailed particulars of the whole of the circumstances bearing on the question are entered before the actual designing is begun.

For Notes on Traffic, Time in answering Calls and Clearing, see Appendix.

CHAPTER XXIV

AERIAL LINE CONSTRUCTION

In the early years of telephony, when the lines were short and the systems employed were simple, almost any kind of outdoor construction was good enough. Now, however, that the C.B. system is being generally adopted, and the lines are subjected to a continual electrical stress by the battery being always connected, the nature of the line construction has become of much more importance, and the highest quality of work and material has become imperative.

Selection of Route.—A great amount of trouble and expense may be saved when lines have to be erected by a careful and judicious selection of the route to be followed. That chosen should be as straight as possible, with a due regard to other considerations, in order to lessen the quantities of materials required, and to prevent excessive strains on the supports. In crossing over thoroughfares in towns, the wires must be at least 30 feet from the ground (in London 35 feet), in order to prevent damage by fire-escapes. The wires should also cross the streets as nearly as possible at right angles, in order that they shall be seen as little as possible, and that if they should break there would be less danger of their falling into the street, to the danger of passers-by. The wires should not pass closely over chimneys, as the heated air and acid vapours very materially weaken the wire, especially during showery weather, when it is subjected to frequent alternations of heat and cold.

In the country, the wires must be kept clear of trees, the branches of which, if touching the wires, give rise to excessive leakage to earth, or may pull the wires together. As permission to run lines along the public roads is somewhat difficult to obtain, recourse must generally be had to private

property, and care must be taken that no damage is done to trees, fences, etc. Poles should be kept near the hedges, and should not be fixed in the middle of fields, or, at anyrate, stays should never be used where cattle would be liable to be injured by them, without some safeguard, such as round wooden blocks fixed firmly to the stay wires to a height of about 6 feet, and with 2 feet buried in the ground. The route should be so chosen that the poles and wires if broken down, cannot fall across the roadways; and in this connection consideration should be paid to the direction of the prevailing winds (which in this country are mostly westerly), especially in exposed situations.

Way-leaves or Easements.—Before the wire can be erected it is necessary to obtain so-called "way-leaves" or "easements," which are formal permissions from the owners of the property for the erection of poles or the attachment of wires to a building. To obtain these is frequently a very difficult matter, and one which requires much tact, judgment, and perseverance. A nominal payment of one shilling per annum is usually made for the way-leave, but often a heavy payment is demanded, and must sometimes be paid.

Railways should be crossed as little as possible, as the railway companies are very exacting in their conditions.

Wire.—Previously to about 1884 the wire used for running telephone lines was mostly of iron, galvanised to protect it from rusting, which, however, it failed to do for long, especially in manufacturing districts, where its life was only about four or five years, and in many places much less. The size of wire used was generally No. 11, or 121 mils diameter, having a resistance of about 24 ohms to the mile.

Copper or bronze wire is now almost exclusively used, and for many reasons is much superior to iron. Copper is used for all trunk lines. As pointed out in Chapter I., it is one of the two best conductors, its resistance being only $\frac{1}{6}$th that of iron. This in itself would have ensured its adoption long ago, but that until a few years ago its mechanical properties were unequal to the requirements. By a process of what is

called *hard-drawing* its mechanical strength was raised from about 6·5 tons per square inch to about 29 tons, and so made it in every way suitable, being stronger than iron, and nearly equal in strength to mild steel. Copper corrodes, but very slowly, in pure atmospheres almost imperceptibly, so that the expense of renewal and maintenance is much reduced, especially in manufacturing districts.

The electrostatic capacity, being proportional to the surface area, is small in thin copper wire. This is a very important matter in long-distance working.

The inductance of iron wire is much greater than that of copper wire of the same form and dimensions, and this up to recent years was considered a great disadvantage for telephonic working, but the mathematical investigations of O. Heaviside, corroborated by recent experiments, have shown that inductance in long-distance lines is actually of advantage, as it serves to neutralise the ill effects due to the static capacity. Unfortunately, the property of magnetic "hysteresis," which is also met with in iron wires, leads to a loss of energy, and a still greater loss is due to what is called the "skin" effect in iron wire, owing to the fact that high-frequency currents, such as telephonic voice currents, do not penetrate far into the interior of an iron wire, but remain near the surface, so that the virtual resistance of such a wire is greatly increased, being equal to that of a hollow tube of the same diameter. These effects more than counterbalance the advantage of the increased inductance, so that copper wire is much superior, and is used for all long-distance lines.

The supports for the lighter copper wire need not be so large or heavy, and another advantage is that the old wire commands a good price as scrap copper.

Bronze Wire.—This is an alloy of about 97 parts by weight of copper and 3 parts of tin. Owing to its tensile strength being about $1\frac{1}{2}$ times that of hard-drawn (H.D.) copper, a small gauge bronze wire (No. 18) is generally used in this country for short sub-station lines. Its resistivity being about $2\frac{1}{4}$ times that of copper is, however, a disadvantage.

Ohm-mile.—The general method of designating line wires is by their weight per mile, such as 100 lb., 150 lb., 200 lb., etc. As the resistances of wires of the same material and length vary inversely as their weights, a very useful constant, called the *ohm-mile,* is obtained by multiplying the resistance of a mile of any sized wire by its weight in lbs. This is really the weight in lbs. of a mile of a wire of the material in question which will have a resistance of 1 ohm, or the resistance of a mile of a wire which would weigh 1 lb. The ohm-mile divided by the weight in lbs. of a mile of any sized wire will give its resistance, and divided by its resistance per mile will give its weight in lbs.

Tensile Constant.—This is another constant, obtained by dividing the tensile strength of a wire by its weight per mile. It represents the length in miles of a wire, which could be supported by its own strength when hung vertically. Multiplying this constant by the weight per mile, gives the tensile strength of any wire of the same material. This, however, is not so reliable a constant, as the strengths of wires in proportion to weight is greater as they become thinner, as is seen in the case of copper wire given in the table below.

	Nearest S.W.G.	Dia. in Mils	Weight in lbs. per mile W	Res. per mile R	Ohm Mile Constant R×W	Tensile Strength in lbs. S	Tensile Constant $\frac{S}{W}$	For what Purpose U
Iron Wire .	8	170	400	12	4800	1425	3·56	Stay Wires
,, ,,	11	120	200	24	,,	713	,,	,, ,,
,, ,,	14	80	90	53	,,	321	,,	,, ,,
,, ,,	16	65	56	86	,,	200	,,	Binding ,,
Steel . . .	10	126	226	27·4	6200	1730	7·66	Cable Suspenders
,,	16	64	58	107	,,	444	,,	,, ,, Strand
Bronze . .	14	79	100	18	1800	485	4·85	Long Junction Lin
,,	16	66	70	26	,,	340	,,	Junction Lines
,,	18	50	40	45	,,	200	...	Short Local Lines
H.D. Copper	8	158	400	2·23	892	1250	3·2	Long Trunk Lines
,, ,,	9	137	300	2·97	,,	950	,,	,, ,, ,,
,, ,,	11	112	200	4·46	,,	650	,,	Shorter ,, ,,
,, ,,	13	97	150	5·95	,,	490	,,	,, ,, ,,
,, ,,	14	79	100	8·92	,,	338	3·38	Short ,, ,,
,, ,,	16	66	70	12·74	,,	234	3·6	Local Lines
Soft Copper	18	48	37	23·7	...	...	...	Binding Wire

Table.—The preceding table gives the strengths, weights, resistances, etc., of the wires mostly used in connection with line work.

Insulators.—As the wire used for telephone lines is generally bare and must be supported at frequent intervals, it is necessary to provide special *insulators*, to which the wire may be attached, and so prevent excessive leakage through the poles, which are not sufficiently good insulators in themselves. In addition to having high insulating qualities, the insulators must have sufficient strength to resist the heavy stresses to which they are subjected.

Material.—This has varied from the original goose-quill to earthenware, glass, ebonite, and porcelain. White porcelain has given the best results; but well-glazed earthenware follows it closely, and has the merit of being cheaper. The principal requirement is that the material must not be porous, and must have a fine glazed surface which is not hygroscopic—that is, has a surface on which moisture will not readily condense.

Experience has shown that leakage does not take place through the body of the insulator, but is altogether a matter of surface conduction by means of the films of dirt or moisture deposited on it.

Form.—In designing the form, the object has been to make the surface over which the leakage must take place as long and narrow as possible consistent with strength, as the law of resistance is the same for films of moisture, etc., as for other substances. A dry portion of such surface must also be preserved in the wettest weather, which object is attained by making the insulator in the form of an inverted cup or cups.

Cordeaux's Screw Insulator.—This is probably the one which answers the above, and certain other requirements to the fullest extent, for which reason it is mostly used for important telephone lines. Fig. 325 shows one form of it partly in section, and the galvanised iron bolt used in conjunction with it. It is a *double-shed* form of insulator, which means that it is in the form of an inverted double cup. *Single-shed* insulators have only one inverted cup. It will be seen

that a great length of surface is opposed to the leakage between the wire (which is fastened in one of the grooves) and the bolt. The screw arrangement shown allows of the insulator being taken apart from the bolt, when in position, for the purpose of cleaning out the inside, or to change the position of the wires on the poles. An india-rubber ring, put over the screw, is sometimes used to allow for the difference in expansion by heat between the iron and the porcelain. The form of Cordeaux insulator used by the British Post Office is rather larger, and has only one groove.

The S.I. Insulator.—Fig. 325 shows the form of Cordeaux insulator used by the National Telephone Co. for all ordinary purposes.

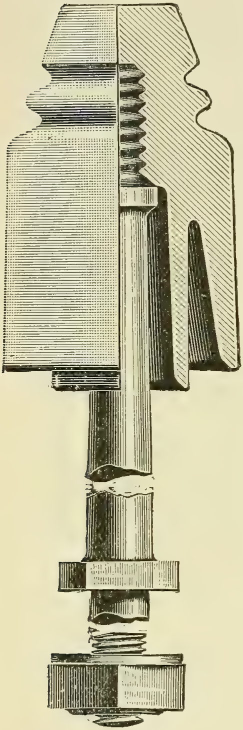


Fig. 325

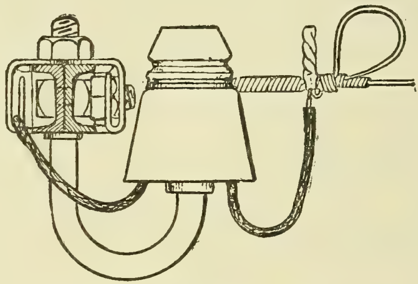


Fig. 326.—Terminating on J Bolt Iron Arm

The straight bolt shown in connection with the Cordeaux insulator, Fig. 325, is only suitable for straight, or nearly straight, through work. For *terminating*—that is, when the wires are cut at the insulator, or where the wires go off at an angle—some form of what is known as the J bolt, Fig. 326, is used. As will be seen, the line of the wires is brought nearly op-

posite the centre of the arm, so that there is no turning stress in a vertical direction. The plane of the bolt also takes the direction of the resultant pull. The J bolt has also another advantage, as it acts as a flexible spring to the wires, giving way a little under excessive stress, due to extreme cold, snow, etc., and thus relieving the wires from excessive strain.

The last figure shows the J bolt attached to an iron arm, and Fig. 327 shows it adapted to a wooden arm. Both these figures also show attachments to the arms, recently adopted, for carrying the leads in a tidy manner. "Double J" bolts are also often used on the ends of arms for accommodating two wires going off at an angle.

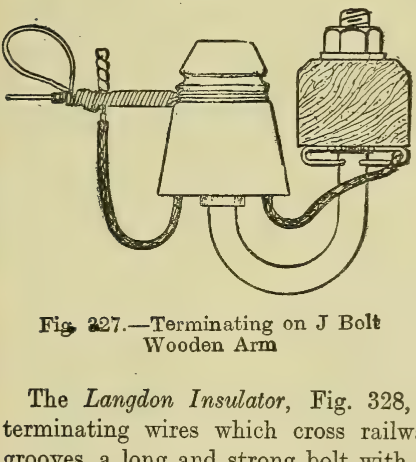


Fig. 327.—Terminating on J Bolt Wooden Arm

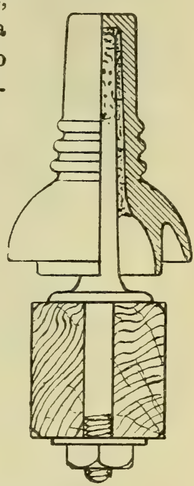


Fig. 328

The *Langdon Insulator*, Fig. 328, is sometimes used for terminating wires which cross railways, etc. It has three grooves, a long and strong bolt with a broad flange, and the grooves are low down. It is not so good as the J bolt and S.I. insulator for strength.

The Bennett Insulator (Fig. 329).—This is a single-shed insulator, and was specially designed by Mr A. R. Bennett to meet the various demands of telephone work. It has been extensively used. It has four grooves, in the two topmost of which wires may be terminated, and if the wire is a light

one both terminations may be made in the top groove. The Bennett insulator is especially strong in resisting damage by stone - throwing, usually a costly item in maintenance.

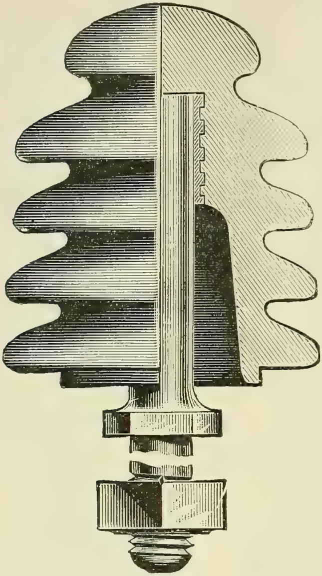


Fig. 329

The S.A. Insulator.—This is a special form, invented by Messrs Sinclair & Aitken, and used where a line terminates and a covered leading-in wire is to be attached to connect to an instrument, or otherwise. As seen in Figs 330 and 331, it is made in two parts, which screw together. The inner cup has a deep recess cut through screw and top large enough to accommodate the leading - in wire, so that when the outer cup is screwed on, the wire is well protected from the wet, surface leakage along the out-

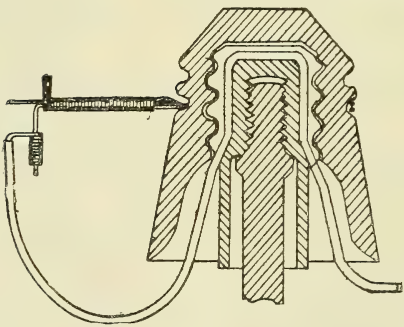


Fig. 330

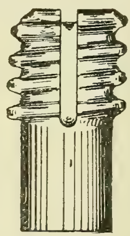


Fig. 331

side of the covered wire being thus prevented by a dry portion being preserved in the cup.

The joint or " nib " should be turned horizontally for easy soldering, and not vertically, as shown in the figure.

Spur Insulator.—This is an insulator of the form shown in Fig. 332, fitted with a grooved boss on the outer shed, so that it enables vertical or nearly vertical wires to be readily attached. It should be double-shed, and should not be used for leading-in terminating at sub-stations unless it is provided with a screening arrangement for the covered lead similar to the S.A. insulator. Some S.A. insulators have lately been fitted with " spur knobs " for the purpose of terminating vertical wires.

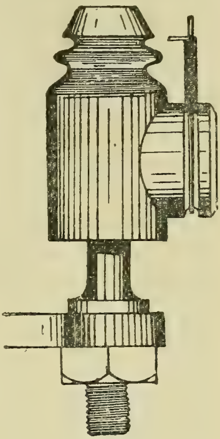


Fig. 332.—Spur Insulator

Wooden poles are used for nearly all but overhouse work for the support of the wires and insulators. They are generally round in section, but square poles are sometimes used to suit the taste of the proprietors of the land on which they are erected.

The poles used are mostly Norwegian or Swedish firs, felled in the winter months, when the sap is least plentiful.

Creosoting.—Before use, the poles should be subjected to some preservative process, of which many have been suggested and tried, but the only one which has so far given satisfaction is *creosoting.* This consists in placing the poles in air-tight cylinders after they have been thoroughly seasoned, and forcing into the pores of the timber a quantity of creosote, an oily and antiseptic product of coal-tar. About 12 lbs. of creosote should be absorbed per cubic foot of timber. This process, if properly carried out, effectually protects the pole from *wet-rot*, which attacks unprotected poles at the ground line, where there are great alternations of temperature and moisture.

Poles up to 75 or 80 feet in length can now be creosoted. When longer poles are required two should be scarfed together,

the top of one and the bottom of a smaller one being fitted together for some 8 or 10 feet, and then firmly clamped with iron bands.

A minor objection to creosoted poles is that they cannot be properly painted, as the oil oozes out. Their appearance is not, therefore, prepossessing.

Sizes of Poles.—Poles are supplied in two classes, *light* and *stout.* The former are for use on routes which are not expected to reach to more than four wires and the latter for all routes likely to attain to more than four wires. Tables giving the sizes, cubical contents and weights are given on page 339. These tables are based on a weight of 56 lbs. per cubic foot for creosoted poles, of which 44 lbs. is for the timber and 12 lbs. for the creosote. Larch poles, which are used where painting is required, weigh about 34·5 lbs. per cubic foot and square pitch pine poles, which are sometimes demanded in residential districts, weigh about 42 lbs. per cubic foot. The weight of square pitch pine poles may be roughly taken as about the same as stout creosoted poles of the same length.

Arming.—Before the poles are erected they should be fitted with the necessary arms. Those used vary in length according to the number of wires they are to carry, the most common lengths being 24, 42, and 76 inches, for 2, 4, and 8 wires respectively. (6-way arms are now obsolete.) They are drilled for insulators so that the wires will be 9 inches apart, except in the centre, where they should be 18 inches apart, to allow space for the workman to get between the wires.

The arms, which are usually of good sound oak about 3 inches square in section, are fitted into slots sawn on one side of the poles at 12 inches apart, centre to centre, and fastened by a bolt, which passes through pole and arm, and is secured by nut and washer, as shown in Figs. 333 and 334, which also show the *pole-roof* of galvanised iron fitted on top of the pole to throw off the rain. These figures actually represent a pole fitted with 4-wire side arms, for use on one side of the pole only. They will, however, also represent one side of 8-wire arms if we suppose the arms extended on the other side and the strut-bar removed.

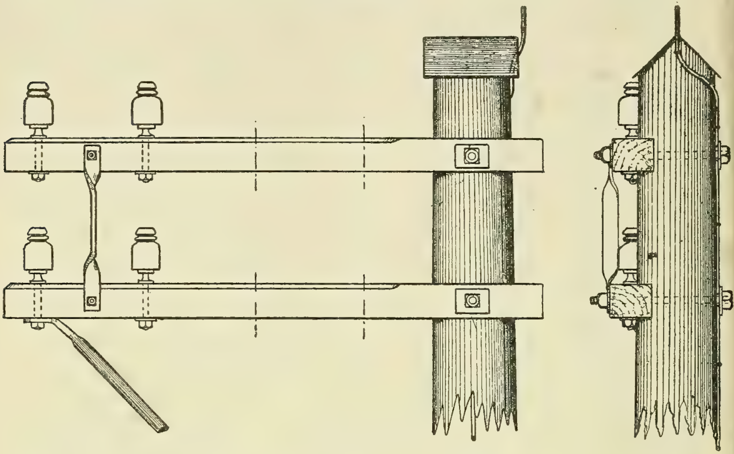
Light Poles

Length	Diameter at Top. Minimum	Minimum Diameter 5 feet from Butt end	Approximate Cubic Contents	Approximate Weight
Feet	Inches	Inches	Cubic feet	Cwts.
24	5	$6\frac{1}{2}$	4·6	2·3
26	5	$6\frac{3}{4}$	5·3	2·65
28	5	7	6	3
30	5	$7\frac{1}{4}$	7	3·5
32	5	$7\frac{1}{4}$	7·5	3·75
34	5	$7\frac{1}{2}$	8·5	4·25
36	5	$7\frac{3}{4}$	9·5	4·75
38	5	$7\frac{3}{4}$	10·5	5·25
40	5	8	12	6
45	$5\frac{1}{4}$	$8\frac{3}{4}$	15	7·5
50	$5\frac{1}{4}$	$9\frac{1}{2}$	19	9·5
55	$5\frac{1}{2}$	$10\frac{1}{4}$	24	12
60	$5\frac{1}{2}$	11	29	14·5
65	6	12	35	17·5

Stout Poles

Length	Diameter at Top. Minimum	Minimum Diameter 5 feet from Butt end	Approximate Cubic Contents	Approximate Weight
Feet	Inches	Inches	Cubic feet	Cwts.
24	$5\frac{1}{2}$	8	6·3	3·15
26	$5\frac{3}{4}$	$8\frac{1}{4}$	7	3·5
28	6	$8\frac{3}{4}$	8·6	4·3
30	6	9	10	5
32	$6\frac{1}{4}$	$9\frac{1}{4}$	11·2	5·6
34	$6\frac{1}{4}$	$9\frac{3}{4}$	12·5	6·25
36	$6\frac{1}{2}$	10	14	7
38	$6\frac{1}{2}$	$10\frac{1}{4}$	15	7·5
40	$6\frac{1}{2}$	$10\frac{3}{4}$	17	8·5
45	$6\frac{3}{4}$	$11\frac{1}{2}$	21	10·5
50	7	$12\frac{1}{4}$	28	14
55	$7\frac{1}{4}$	13	33	16·5
60	$7\frac{1}{2}$	$13\frac{1}{2}$	40	20
65	$7\frac{1}{2}$	$14\frac{1}{4}$	45	22·5
70	$7\frac{1}{2}$	$14\frac{3}{4}$	50	25
75	8	$15\frac{1}{4}$	55	27·5
80	$8\frac{1}{2}$	$15\frac{3}{4}$	65	32·5
85	$8\frac{1}{2}$	$15\frac{3}{4}$	75	37·5

Earth Wiring.—The same figures also show the earth wire of No. 8 galvanised iron, which is made into a coil at the bottom of the pole, stapled up the back, then screwed under the nuts and washers of the arm bolts, and finally terminated



by a free end projecting about 3 inches above the pole-roof. It is sometimes also screwed under the insulator bolts. This wire is intended to act as a safeguard in case of lightning.

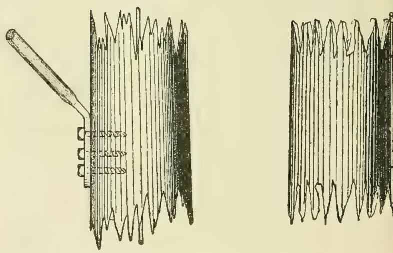


Fig. 333.—Scale $\frac{1}{16}$ Fig. 334
Pole with Side Arms

Combiners.—8-way arms have extra holes drilled horizontally near the outer ends for the attachment of iron "combiners," which bind the arms together, as shown in Fig. 333, and add to their strength and rigidity. The strut-bar shown in Fig. 333 is only used on side-arm poles.

Erection of Poles.—After the arms have been fitted (and taken off again) the poles are planted in the earth to a depth

proportional to their length, varying from about $\frac{1}{6}$th to $\frac{1}{11}$th as per table below.

Length of Pole	Depth in Ground	Length of Pole	Depth in Ground
24 feet	4 feet	48 feet	6 feet
28 feet	4 feet 4 inches	55 feet	6 feet 6 inches
32 feet	4 feet 8 inches	65 feet	7 feet
36 feet	5 feet	75 feet	7 feet 6 inches
40 feet	5 feet 4 inches	85 feet	8 feet
44 feet	5 feet 8 inches	...	...

If the ground is soft, the depth should be greater, and if hard, rocky ground, less. If the earth is very soft the butt of the pole should be made to rest on a flat plank to give a larger bearing surface and so prevent sinking.

In digging the hole an oblong space is first marked out only a little wider than the butt of the pole (so as to have solid earth on three sides of the pole), and 4 or 5 feet long; the longest side if possible being parallel with the line of the wires to be erected. This space is then dug out in steps until the end where the pole is to rest has reached the proper depth. This is called "stepping."

The pole is then brought to the hole, so that the butt lies over the deepest part. It is next tilted up, and three or four strong ladders of different lengths are put under the top end. By means of a couple of men or so at each ladder the pole is gradually raised a few inches each lift, the ladders being shifted in position one at a time, so as to keep them as near right angles to the pole as possible, to get the best lifting effect, and prevent slipping. This is further prevented by passing light ropes over the tops of the ladders after having been fastened at the top of the pole.

Fig. 335 will give an idea of the method—A showing the form

of the hole, B the pole, C, D, E the ladders, longer ladders being used as the pole becomes more upright, when it is steadied by the ropes attached to the top. At F a board is shown at the end of the pole. This is to prevent the end of the pole digging into the soil, and so impeding its erection. The sides of the hole prevent the pole falling over sideways. When the pole is upright the earth is filled in, and well rammed or *punned* down with punning tools. This punning is very important,

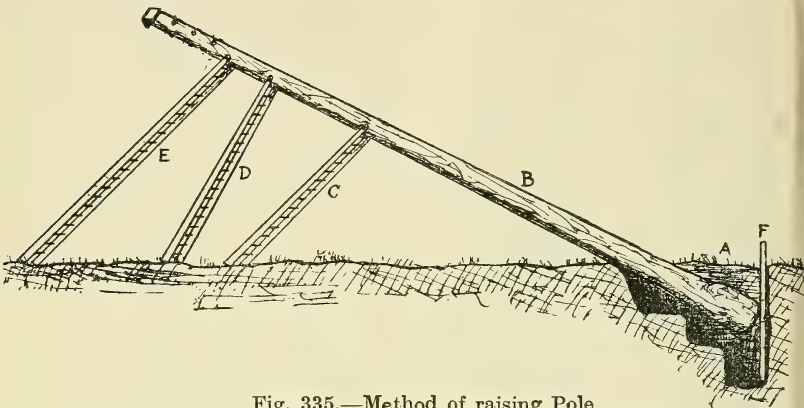


Fig. 335.—Method of raising Pole

and should on no account be scamped, as the stability of the pole depends altogether upon it.

In America, instead of ladders, so-called "pole-pikes" and " ead-men" are used for raising the poles. The former are stout and strong wooden rods about 15 feet long, fitted at the end with a steel spike, so as to fix in the pole. A "dead-man" is a sort of cradle, also fitted with a spike or blade (as shown in Fig. 336), which is used to support the pole while the positions of the "pole-pikes" are being altered after the pole has been partly raised. The "dead-man" is also fitted with a spike at its lower end. Whilst these tools are handier and lighter than ladders, they are not so generally useful.

When exceptionally large poles have to be raised, or poles have to be put in positions where ladders cannot be employed,

a smaller pole is erected in some convenient position to be used as a *derrick.* Pulley blocks are attached to the pole above an arm bolt at the top of the derrick pole, and to about the centre of the pole to be raised. Another pulley block, called a snatch block, is also fitted to the bottom of the derrick pole, as shown in Fig. 337. By means of these appliances the pole can be swung round, and its ends moved into position, and then, by ladders and thin ropes, called *sash lines,* it is brought to an upright position. Walls have often to be taken down before the work can be completed, and the skill of the men is often taxed in effecting the purpose.

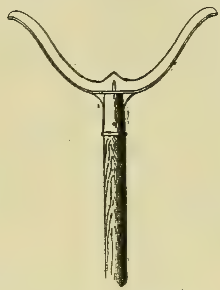


Fig. 336.—Dead-Man for Pole-raising

If there is to be a side pull on the pole it should be so planted that it leans slightly, or is "set" away, from the pull, so that the stress will draw it to an upright position, or very nearly so.

Iron brackets or *steps* are strongly screwed on both sides of long poles to enable the workmen to gain the top. They are fixed alternately on either side, so that they form steps 15 inches apart vertically or 30 inches on each side.

When terminating, and in other cases, the arms should be so fitted that the pull draws them towards the pole instead of against the head of the arm bolt.

Under ordinary conditions the poles should be about 65 yards apart, or 27 poles to the mile, but the number may vary between 22 and 30 to the mile according to circumstances.

Strength of Ropes.—For the men's safety it is very important that the sash lines and ropes used shall be of adequate strength. Manila ropes are generally used, the sizes being based on their circumferences; thus a 3-inch rope means one which is 3 inches in girth. Ropes should be kept dry as they lose a great deal of their strength when wet. The breaking strength in pounds of a manila rope is given by $S = 605G^2$. G being the girth in inches. The safe working load $L = 121G^2$. S and L for tarred

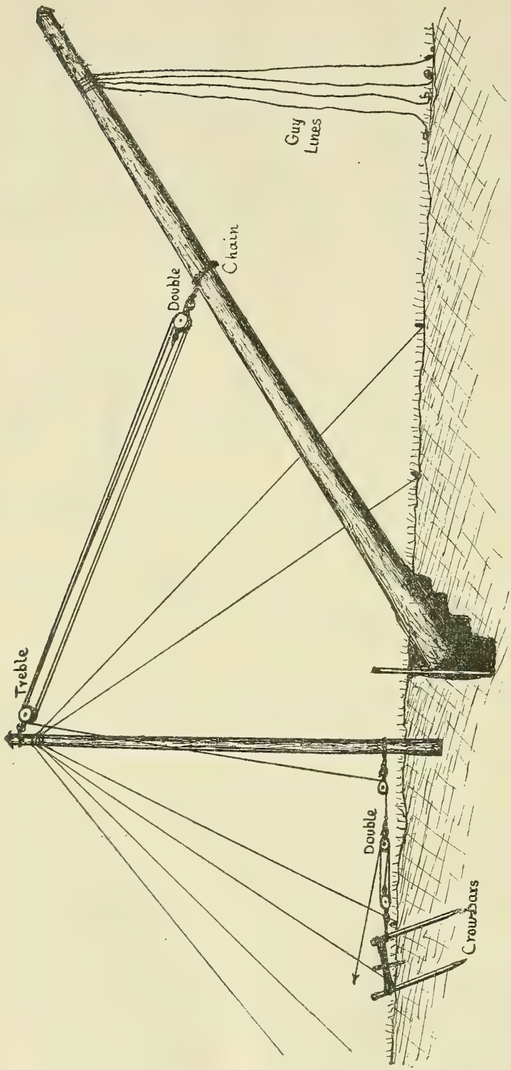


Fig. 337.—Method of raising Heavy Poles

hemp ropes is about 20 per cent. less and for white hemp about 6 per cent. higher than for manila.

Stays.—When a pole is subjected to heavy stress by the wires going off at an angle, *stays* or *guys* are used to prevent the pole going over in the direction of the strain. They are usually made up of five or seven No. 8 galvanised-iron wires twisted together. One end of this is taken twice round the top part of the pole, and finished off as shown in Fig. 338, the best position being midway between the top and bottom arms, so that it may act at the *resultant* point of the total pull of the wires on the pole, but in any case the stay should not be needed to come within less than about 3 feet of the top of the pole, as such a length of the pole is stiff enough to resist bending, and allowance will be left for extra arms to be added at some future time.

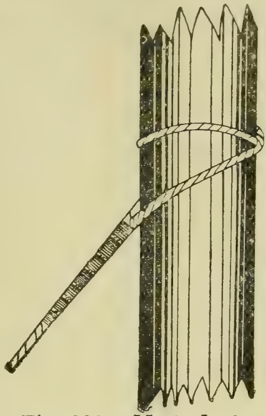


Fig. 338.—Method of attaching Stay Wire

A hole is dug as far from the foot f the pole as is convenient, and in this hole a block of creosoted timber is placed, through which a long bolt, called a *stay rod*, provided with a large *washer plate*, is passed. The hole should be undercut, as shown in Fig. 339, so that the pull may be against solid earth.

An experimental test showed that an 8-feet stay rod with block buried 5·5 feet deep was pulled up with 7000 lbs. in newly rammed earth but required 35,550 lbs. when fitted in an undercut position as in Fig. 339. The top of the stay rod is fitted with a *bow-swivel*, furnished with a *thimble*, round which the stay wire is fastened. The bow-swivel is so arranged that by turning a nut the stay wire can be tightened up. Thimbles should always be used in making off the stay wires on to bows, etc., to prevent cutting. Two or three stays are required where the strain is excessive.

Straight and heavy routes should be stayed at intervals, both in a direction at right angles to the lines, and also in the same direction, the latter being called "fore-and-aft" staying. The former is to withstand the side pressure of wind on the wires and poles, and the latter to prevent the whole line giving

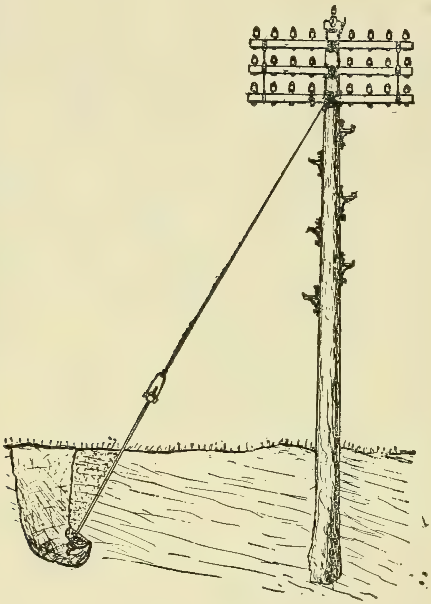


Fig. 339

way if any one or more poles should break down and both kinds help to keep the wires in good regulation.

Struts.—In cases where a stay cannot conveniently be fixed a strut is used, which consists of a rather shorter pole fixed at an angle to the main one, and on the same side as the pull of the wires. A block of creosoted timber is attached to the foot of the strut by means of an iron strap, and this is buried about 4 feet in the ground. Struts should be avoided if possible, as they are not nearly so satisfactory as stays.

In attaching the strut to the pole the latter should not be cut into, but the top of the strut should be cut out to the curve of the pole, and fixed by a long bolt with nut and bevelled washer, as shown in Fig. 340.

In some cases when stays or struts cannot be used it is better to *truss* the pole, as shown in Fig. 341, where an *out-rigger*, A, is screwed to the pole on the opposite side to the pull (the direction of the latter being shown by an arrowhead), and a strong stay is passed through an eye in the end of the outrigger, and attached to a stay rod and block buried near the foot of the pole, the stay rod being provided with a *stay tightener* to strain the stay as shown at B.

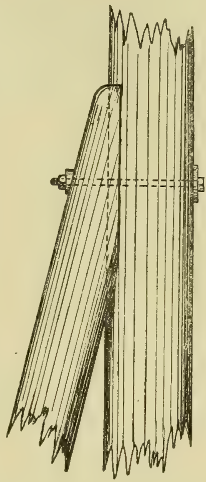


Fig. 340.—Pole Strut

The ground resistance to the pole should be strengthened by fixing stay blocks at right angles and on opposite sides of the pole, as shown at C and D, so that the pull of the wires will tend to press the pole against each of the blocks. This plan should be adopted with ordinary poles where the ground is soft and yielding.

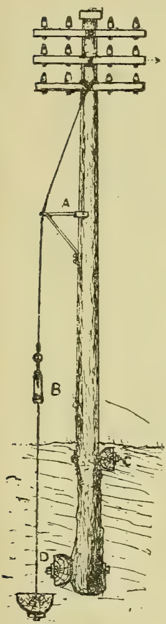


Fig. 341.—Trussed Pole

OVERHOUSE WORK

In good modern work in towns nearly all the wires are carried in underground cables; but it is still necessary to run a number of wires overhead for the distribution of the lines from the ends of the cables, which are usually terminated on what is called a *distributing* pole. These, where

possible, should be ground poles, but in towns cases arise where roof poles are a necessity.

Iron Poles.—For greater neatness and lightness, the poles

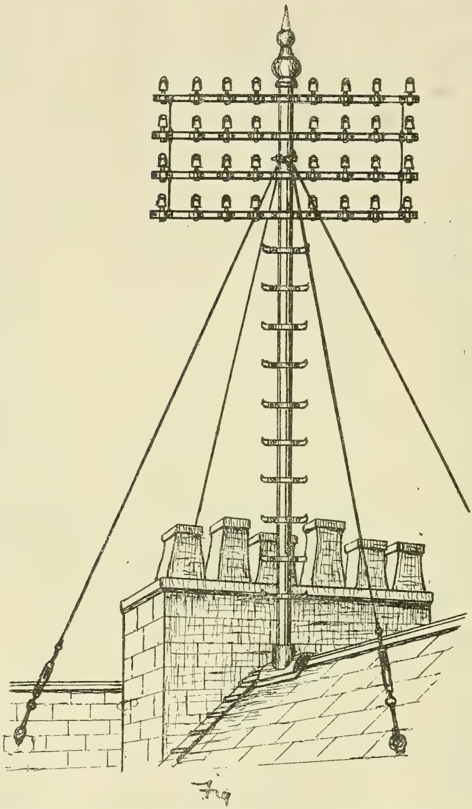


Fig. 342.—Iron Pole complete with Arms, Stays, etc.

and arms are constructed of iron or mild steel, on the model introduced about 1881 by Mr A. R. Bennett.

Fig. 342 shows one of these poles and the method of fixing on the roof ridge of a building. Special cast-iron "pole-chairs" are used in this case, shaped to fit over the ridge,

after the ridge tiles have been removed, and layers of sheet lead and two thicknesses of roofing felt have been laid, as a bedding for the chair. A better position is, however, on one of the main walls of a building, as shown in Fig. 362, which is the position to be chosen when possible. The upright part in Fig. 342 is a single wrought-iron tube, 4 inches outside diameter and about 18 feet long, the foot of which is tightly wedged in a socket formed in the *pole-chair*, which in its turn is bedded on three or four thicknesses of roofing felt. Sometimes the pole is supported on a girder fitted across the main walls, in which

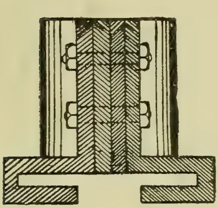


Fig. 343

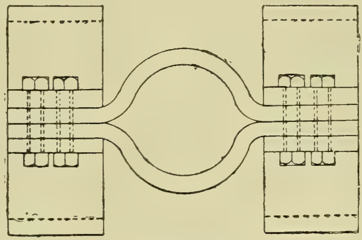


Fig. 344

case a *girder clip*, Figs. 343 and 344, is employed, made in different sizes for various girders.

Tubes for these poles are made 4, 4½, and 5 inches diameter, the metal being ¼-inch thick, so that the smaller tubes fit into the next size above. The usual lengths are 8, 10, 15, and 18 feet. Many poles are formed by two or more tubes, one fitted inside the other for a length of about 2 feet, and secured by two bolts passing through the tubes. Poles of 40 feet or more in length may thus be obtained.

Iron Arms.—Fig. 345 gives a view of one of the arms on a larger scale. They are formed of four lengths of channel iron, so shaped that when screwed together by the bolts shown they grip the tubes, and leave spaces for the bolts of four insulators. The arms thus formed are 42 inches long, for 4-wire arms as shown, the 8-wire arms being 78 inches long. The dimensions are shown in the sketch, and Fig. 326 gives a section, with bolts

and nuts on a larger scale. Arm combiners are clamped by longer bolts provided, as shown in Fig. 345. These are employed whenever more than one arm is used.

Staying.—Iron poles must be well stayed, as they have no lateral strength by themselves. At least four stays must be attached to the shortest, and longer poles made up of two or three tubes should have at least eight—four fixed near the top, and the others at the next joint below. Each of the stays should be provided with a stay tightener or *screw-swivel*, and the lower end should be attached preferably to a wall plate, securely nailed to the outer main wall of the building. If this cannot be done, the stays may be attached to the main timbers

C.A.4.
(a & b)

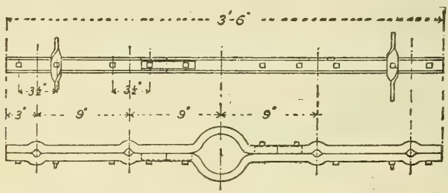


Fig. 345.—4-Wire Channel-Iron Arm

of the roof by means of rafter swivels and pivot hooks, which are fixed by a bolt passed through the timbers, but they must be carefully made off with lead, etc., to prevent leakage of rain; or the stays may be attached to iron-wire bands passed round heavy chimney stacks, the corners of the stacks being protected by angle plates. Two or more stays may be attached to the same wall plate or other fixing, but each should be provided with a separate "thimble."

The staying of iron poles is very important, and great care should be taken that it is thoroughly well done.

Double poles are made up of two, and triple and multiple *standards* of three or more upright poles connected by special long arms, providing for 8, 12, and 16 wires. From the larger sizes of these, Exchange Standards can be constructed of 3, 4, or more sides. Fig. 346 gives a view of such a square standard made up with eight uprights. When such structures as these

are used, it is necessary to strengthen the roof by means of iron

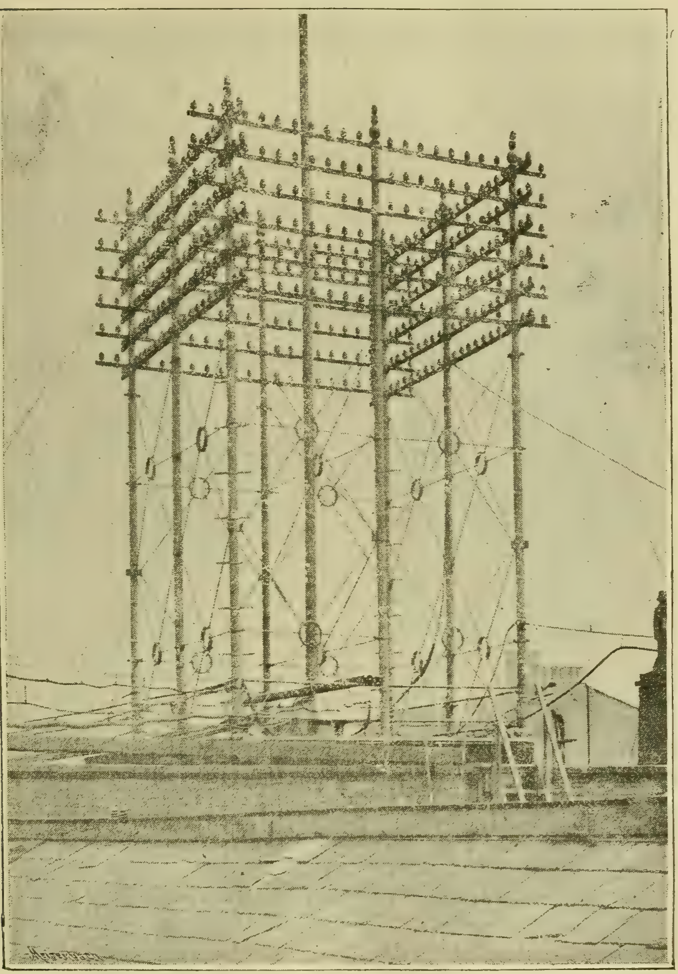


Fig. 346.—General View of Exchange Standard

girders built into the walls, so as to give a firm and rigid fixing.

Chimney Brackets.—Wires should only be attached to strong chimneys, and the form of double bracket shown in Fig. 347 should be used, this being attached by two bands (only partly shown) each of two No. 11 galvanised-iron wires, passed right round the chimney; iron angle plates being fitted at the other three corners for the bands to bed upon. Care should be taken that the tension of the wires tends to press the bracket against the chimney.

Corner Brackets, Fig. 348, are fitted on corners of buildings

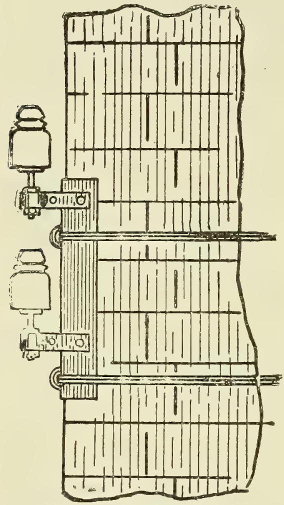


Fig. 347.—Method of attaching Chimney Brackets

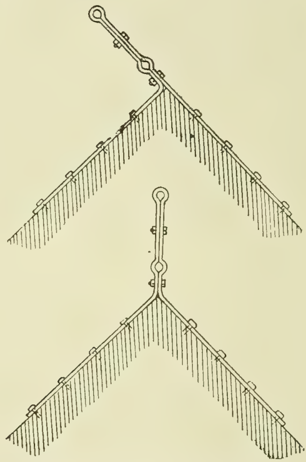


Fig. 348.—Corner Brackets Scale $\frac{1}{24}$.

where nails can be used to fasten them. Each accommodates two insulator bolts.

Eaves Bracket.—Fig. 349 shows the form of bracket used for carrying wires over the edges of the roofs of buildings, and shows a spur insulator for the running of open wires straight down a wall. Two insulators are carried on the cross-piece of the bracket; but only one is shown in the drawing, the other being hidden behind.

Sockets and Straps for Extensions.—For leading-off branch

wires, tubular sockets and straps having holes at each end are employed. A pair of straps are used which are fitted on the insulator bolt at the end of the arm, one strap above the arm and the other below. At the other end of the straps the shank of a "J" bolt, single or double, is passed through, with tubular washers to keep the straps the proper distance apart.

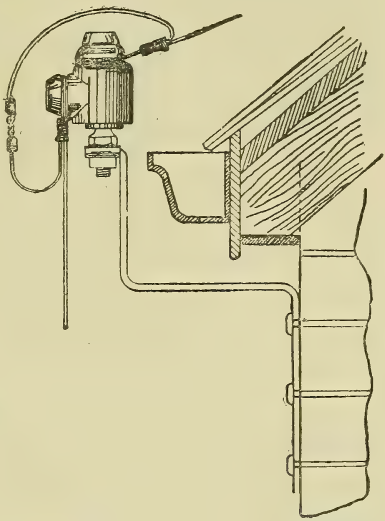


Fig. 349.—Eaves Bracket and Spur Insulator

In order to save the necessity of cutting the wire and taking out the insulator bolt to put on the top strap when it is required to extend working wire arms, the writer devised the double strap shown in Figs. 350 and 351. This can be fitted over the bolt when the latter is knocked up for about $\frac{3}{4}$ inch, and when the two halves are closed, and the bolt screwed up, they bind each other by means of the projections shown on the ends, and thus prevent opening out. A pair of these straps takes the place of one of the ordinary straps.

Sourdines or "Deafeners."—Complaint is often made of the noise caused by the vibration or *humming* of wires attached to a building. A very simple method of preventing this is to bind a strip of lead about 27 inches long, $\frac{1}{8}$ inch thick and $\frac{1}{4}$ inch wide, tightly round the wire for about 8 inches on each side of the insulator. A layer of spun yarn under the lead makes the device still more effective.

Wiring.—40-lb. bronze wire is supplied from the maker in

coils of from 20 to 40 lbs. in weight; 100-lb. copper wire in coils of from 50 to 125 lbs., and 18 inches in diameter. It should not be directly unwound from the coils, or it would be apt to get into kinks and twists. A kind of wheelbarrow provided with a drum, on which the coil fits, is used, from which the wire may be unwound under tension.

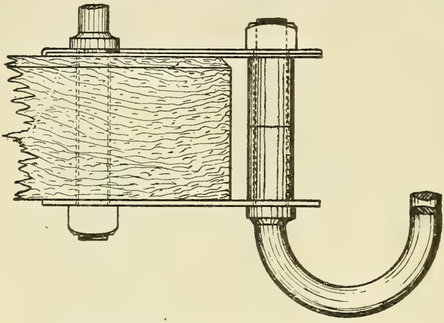


Fig. 350.—Elevation (Scale $\frac{1}{4}$)

On straight runs in the country the wires are "terminated" at about every sixth pole, being simply bound to the insulators of the intermediate poles. This is done to prevent the line wire running back for a long distance if a span should break. Terminating is also needed when a covered wire is to be connected for leading in.

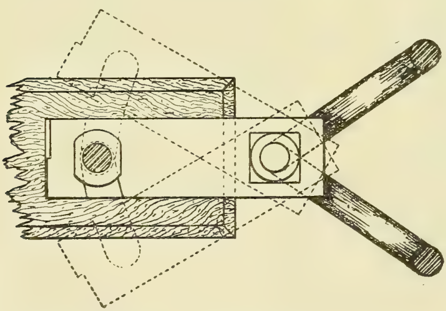


Fig. 351.—Plan (Scale $\frac{1}{4}$) Poole's Extension Straps

Jointing.—Formerly all joints in line wires were completed by soldering, as it was considered that our damp climate would not allow of the use of the mechanically twisted sleeve joints used in America, and generally known as McIntire joints. Experiments carried out by the National Telephone Co. have, however, shown that such joints are perfectly reliable, as they appear to entirely exclude the air and moisture from the surfaces in contact, and they have consequently been adopted.

The joints are made by means of flattened soft copper tubes of three different sizes, $2\frac{1}{2}$, 3 and 5 inches long for 40-lb. bronze and 100 and 150 lbs. copper wires respectively.

A sleeve is slipped on the ends of the wires to be joined (after the ends have been carefully cleaned with emery cloth), and then by means of two special jointing clamps of the form shown in Fig. 352 having three grooves to accommodate the

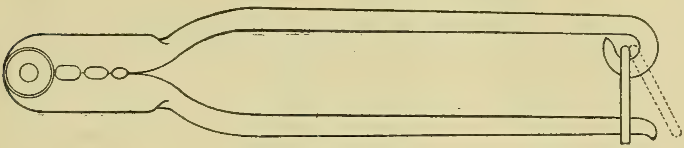


Fig. 352.—Jointing Clamp

three sizes of sleeves, the sleeve is given four turns of twist for the two smaller sizes and five for the largest, when straight-through joints are being made. Fig. 353 shows a side and end view of the 100-lb. copper sleeve and also the joint completed.

Terminating with Bronze Wire.—A length of 40 inches of wire is to be allowed beyond the centre of the insulator. At a point 13 inches beyond the centre of the insulator the wire is to be

Fig. 353.—Copper Sleeve Joint for 100-lb. Copper Wire

doubled back on itself, the loop thus formed being taken round the bottom groove of the insulator and then bound tightly and closely in twelve turns of the bight (twenty-four turns of wire) round the main-line wire and the end which has been doubled back. The end of the wire is next brought back so as to form a loop of about 2 inches diameter and bound over the first binding until about 2 inches is left, the end of which is inserted with the end of a leading-in wire into the same end of a $1\frac{5}{8}$-inch sleeve. Two turns of twist are given to complete

the joint and the outer end is cut off as far as the twist. The 2-inch loop is used to allow for new joints after disconnecting for testing, etc. Fig. 354 shows the complete joint and Fig. 355 shows a double termination, the spare wire of the single joint

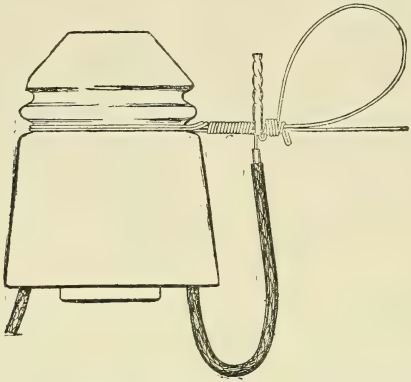


Fig. 354.—Single Terminating of 40-lb. Bronze Wire

being wound in opposite directions round the bottom groove instead of being made into loops. Only a 36-inch length of each wire is needed beyond the centre of the insulator instead of 40 inches, and the wire is doubled back at 11 instead of 13 inches.

Terminating with Copper Wire.—The middle of a binder of No. 18 wire 34 inches long must first be passed round the bottom groove, and twisted together for one or two turns close to the insulator, leaving the two ends to form a double binder. The end of the line wire is then brought once round the bottom groove of the insulator, above the binder, and laid by the side of the main wire and cut at a distance of 17 inches from the centre of the insulator. The doubled binder must

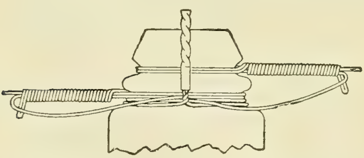


Fig. 355.—Double Terminating of 40-lb. Bronze Wire

then be tightly and closely wrapped round the two for a distance of 2 inches, the end (or nib) of the line wire being turned outward, and the binder continued for five or six turns along the main wire. The end of the line wire is then brought

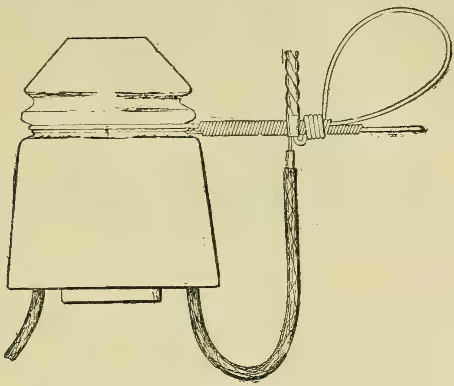


Fig. 356.—Single Terminating of 100-lb. Copper Wire

back so as to form a loop of about 2 inches diameter and finished off as with the bronze wire joint, a $1\frac{3}{4}$-inch or 2-inch sleeve and a packing tube being used to complete the joint, which is shown in Fig. 356.

Packing Tubes.—These are soft copper cylindrical tubes used

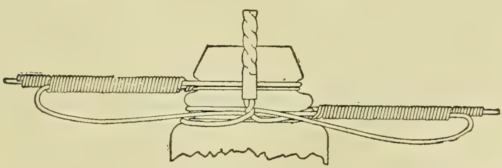


Fig. 357.—Double Terminating of 100-lb. Copper Wire

when two different sized wires are being jointed to slip over the end of the smaller wire to bring it up to the size of the larger one before inserting in the jointing sleeve.

Fig. 357 shows a double termination with copper wire which is similar to two of the single copper terminations except that

the spare wire is taken round the bottom groove of the insulator, as in the case of the bronze wire double termination, the same lengths of wire and doubling back being allowed also as with the bronze.

Line Fuses.—Fig. 358 shows the method of fitting a line fuse at the point where a leading-in wire is connected to a line.

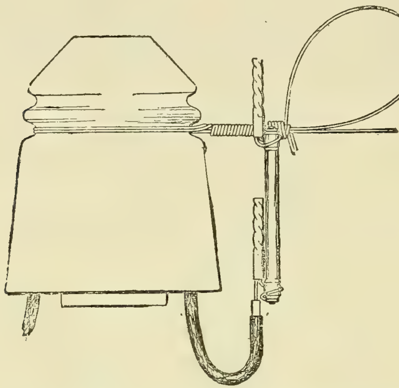


Fig. 358.—Method of fixing Line Fuse

Two complete twists are given to both the sleeves, and the ends are cut off as before.

Binding.—This is necessary when a line wire is not terminated but runs right through to another pole. It is done in the following manner :—The binding wire, 36 inches in length, is neatly and tightly whipped round the line wire for about $1\frac{3}{4}$ inches (this is done to prevent chafing of the line wire by friction against the insulator) ; the ends are then passed round the insulator in reverse directions, and under the line wire, round which they are again wrapped for two turns ; they are then once more passed round the insulator, and finally whipped round the line wire for a further seven or eight turns, and cut off close. Care should be taken not to bind in so tightly as to put a sharp bend in the line wire. Fig. 359 shows the joint when completed.

For the very heavy wire (sometimes as much as 800 lbs. to the mile) used by the British Post Office authorities for the telephone trunk lines, copper tape or a length of wire flattened

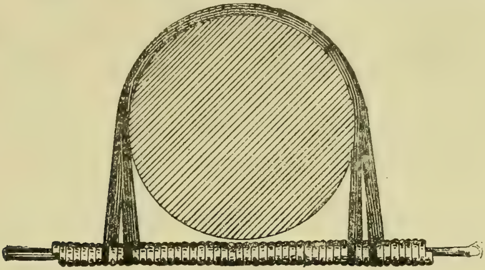


Fig. 359.—Binding Line

at each end is used for binding, the line wire being first wrapped with a separate length of tape.

The *Britannia Joint* is used when two copper wires are to be joined together without a sleeve. Fig. 360 shows how this

Fig. 360.—Britannia Joint. Scale $\frac{2}{3}$

should be made. Such joints should only be made near an insulator, as, if in the middle of a span, the wires are more likely to swing into contact. For wires of less than 100 lbs. per mile no separate binding wires are used, the two ends being

Fig. 361.—Twisted Joint. Scale $\frac{2}{3}$

twisted and made off as shown in Fig. 361. The joints in each case are about $2\frac{1}{2}$ inches long.

Aerial Cables—Where underground facilities cannot be obtained, and overhead wires to the number of more than about twenty-five have to be run along the same line of poles, it is generally more economical to use aerial cables than to run open wires for the purpose.

The cable used almost exclusively for this purpose until lately was what is known as "dry-core" (for a description of which see next chapter), with a covering of vulcanised india-rubber and an outer covering of ozokerited tape. This type of cable is very light and flexible, but as it is not so durable as lead-covered cable its use has been discontinued, except for special circumstances, in favour of lead-covered aerial cable.

The great weight of the lead-covered cable makes it necessary that the supports shall be of greater strength than was needed for the rubber cable, and the liability of the lead sheathing to damage, by bending, etc., renders a much greater degree of care necessary in its handling. When, however, it has been carefully erected, there appears to be little or no deterioration, and its life may be taken as at least 15 years. The scrap value of this cable when worn out is much greater than that of rubber cable, being about one-third of the value in the case of lead and only about one-tenth in the case of rubber.

Cable Suspension.—Cables are not in themselves strong enough to support their own weight overhead, and they are therefore carried by strong "suspenders," which are made up either of two or more "single" No. 10 S.W.G. steel wires, or is a "stranded" suspender made up of three or more wires twisted together to the number and sizes given in the tables on page 361.

The wires of the single wire suspenders are "made off" separately on the supports, which are generally the lower part of poles or standards, as shown in Fig. 362. The first wire being pulled up to a tension of 600 lbs. (whatever the temperature), and the end is then passed twice round the pole and bound to the "standing part" by twelve turns of No. 16 galvanised iron wire. The other wires are next pulled up so as to be parallel to the first and made off in a similar manner.

The "stranded" suspenders are pulled up to an initial tension of 600 lbs. for every 225 lbs. weight (the weight of No. 10 S.W.G.) per mile of the suspender as shown in the tables. Thus a $\frac{3}{250}$ lbs. suspender is pulled up to a tension of $\frac{3 \times 250 \times 600}{225} = 2000$ lbs. The "making off" in this case is

Lead-covered Aerial Dry-core Cables

10 *lbs. per Mile Conductors*

No. of Pairs	Weight per Foot	Extent of Diameter	Number of Single Suspending Wires and Size of Strand								Length of Joint	
			Not over 120 Feet		121 to 150 Feet		151 to 180 Feet		181 to 210 Feet		Between Lead Coverings	Lead Sleeve
			Single	Strand	Single	Strand	Single	Strand	Single	Strand		
	lbs.											
10	·53	·478	2	$\frac{3}{150}$	2	$\frac{3}{150}$	2	$\frac{3}{150}$	2	$\frac{3}{150}$	12	4 ins. longer than Joint
15	·63	·536	2	,,	2	,,	2	,,	2	,,	12	
25	·88	·640	2	,,	2	,,	3	$\frac{3}{250}$	3	$\frac{3}{250}$	14	
35	1·06	·720	2	,,	2	,,	3	,,	3	,,	14	
50	1·27	·830	3	$\frac{3}{250}$	3	$\frac{3}{250}$	4	,,	4	$\frac{7}{150}$	14	
75	1·53	·932	3	,,	4	$\frac{7}{150}$	4	$\frac{7}{150}$	5	,,	14	
100	1·89	1·100	4	$\frac{7}{150}$	5	,,	5	$\frac{7}{200}$	6	$\frac{7}{200}$	19	
150	2·35	1·250	5	,,	6	$\frac{7}{200}$	6	,,	7	$\frac{7}{206}$	19	
200	2·81	1·400	6	$\frac{7}{200}$	7	$\frac{7}{250}$	8	$\frac{7}{250}$	8	,,	22	

20 *lbs. per Mile Conductors*

No. of Pairs	Weight per Foot	Extent of Diameter	Number of Single Suspending Wires and Size of Strand								Length of Joint	
			Not over 120 Feet		121 to 150 Feet		151 to 180 Feet		181 to 210 Feet		Between Lead Coverings	Lead Sleeve
			Single	Strand	Single	Strand	Single	Strand	Single	Strand		
	lbs.											
10	·68	·56	2	$\frac{3}{150}$	2	$\frac{3}{150}$	2	$\frac{3}{150}$	2	$\frac{3}{150}$	12	4 ins. longer than Joint
15	·80	·62	2	,,	2	,,	2	,,	2	$\frac{3}{250}$	14	
25	1·22	·874	3	$\frac{3}{250}$	3	$\frac{3}{250}$	4	$\frac{3}{250}$	4	$\frac{7}{150}$	14	
35	1·56	1·000	3	,,	3	,,	4	,,	4	,,	14	
50	1·96	1·140	4	$\frac{7}{150}$	5	$\frac{7}{150}$	5	$\frac{7}{200}$	5	$\frac{7}{200}$	19	
75	2·51	1·350	5	$\frac{7}{200}$	6	$\frac{7}{200}$	7	$\frac{7}{250}$	7	$\frac{7}{250}$	19	
100	2·96	1·510	6	,,	7	$\frac{7}{250}$	8	,,	8	,,	22	

done by passing the suspender twice round the pole and then clamping the end to the standing part by a special plate clamp.

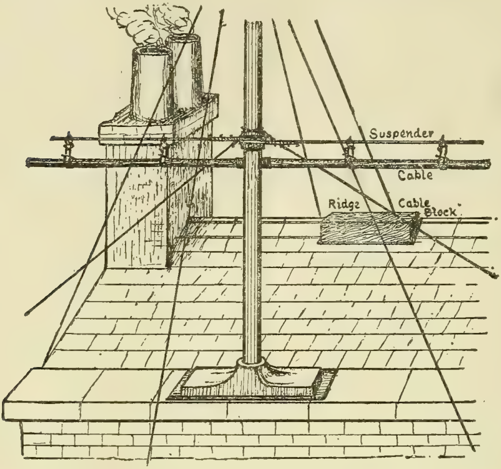


Fig. 362.—Method of supporting Cable

The span for lead-covered cables should seldom exceed 70 yards, so as to keep the sag small, and thus prevent excessive swinging, which is injurious to lead-covered cable. If it is necessary to have longer spans than 70 yards rubber-covered D.C. cable should be used for the purpose, or the lead-covered cable should be supported on "ridge-blocks" fixed on intervening roofs. Such a block is shown in Fig. 362.

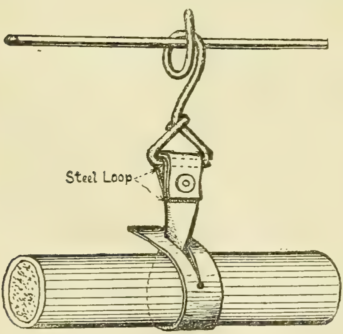


Fig. 363.—Cable Sling. Scale $\frac{1}{4}$

The cable is supported from the suspenders at every two feet by raw-hide slings, one of which is shown in Fig. 363. The loop of the hide round the

hook is strengthened by a flat loop of steel, which is riveted with the hide by the copper rivet.

Dip or Sag.—The amount which a wire falls at the centre of the span when its points of suspension are at equal heights is called its *sag* or *dip*. There will always be some sag, no matter how tightly the wire is stretched.

In dealing with the relation between stresses and sags of wires at various temperatures it was until recently assumed that the only alteration in the length of the wire of a given span was due to the temperature effect, from which it followed that the stress on the wire is the greater the lower the temperature owing to its contraction.

It was further settled that the stress at the lowest winter temperature (which was taken as 22° F.) should not exceed the breaking stress of the wire divided by some "*factor of safety*," to allow for extra stresses due to wind and snow. This factor has been taken at 4 and also at 3. From the results of certain experiments and tests it seems likely that 2·5 is a more correct figure. On the basis of a factor of safety of 3 and 4 tables were made out giving the sags for different lengths of spans at 22° F., and also at various temperatures, when the sags would be greater owing to the wire expanding.

In practice, however, it was found that the amount of dip given by the men was much less than that shown in the tables; and yet the wires did not break at the low temperatures, as they should have done according to theoretical considerations.

Elasticity.—The above facts directed special attention to the subject, and it was found that a very important point had been left altogether out of account. This was, that as the tension on a wire increases, its length also increases quite apart from the temperature effect, owing to the actual stretching of the material, as with a length of india-rubber but to a much less extent. The effect of this is, that when a wire contracts by cold the stress or tension is thereby increased, and this results in the wire stretching a little more than before, so that the resultant alteration in the length, stress, and dip is not so great as it would otherwise have been, and thus the breaking stress is not so soon reached by

a reduction of temperature. (For further particulars and formulæ the reader is referred to an article by B. Hopkinson on "Sag and Strain in Trolly Wires" in *The Electrician* for 25th January 1901.

If the stress on the wire does not exceed a certain proportional part of its breaking stress (which in H.D. copper wire may be taken at $\frac{2}{5}$ths and for bronze wire also at $\frac{2}{5}$ths) the elasticity of the wire is perfect, and it assumes its former length exactly (and therefore the same sag) when brought back to the same

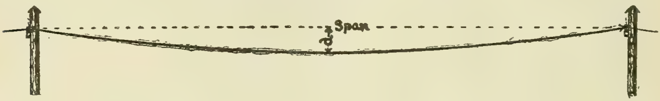


Fig. 364.—Curve of Wire Span

conditions of stress and temperature. If, however, this proportional stress is exceeded, its "elastic limit" is passed, the wire gives way, and the relative stresses and sags are permanently altered. When the stress on the wire approaches the breaking point this permanent stretch takes place, the sag is therefore increased, and the stress relieved. See next page for formulæ, etc.

Catenary Curve.—The curve (Fig. 364) taken by the suspended wire is known as the *catenary*, and is similar to that taken by a chain freely suspended at both ends. From the properties of this curve it follows that the stress on the wire is the greatest at the highest point of the curve, being as much greater at this point than at the lowest or horizontal point, as the weight of a length of the wire equal to the difference in height or equal to the dip. With telephone and telegraph wires the difference is so small that it may be neglected. The formula given below very nearly expresses the relations between the stress (t in lbs.), the weight of wire (w = weight of 1 foot in lbs.), the length of span (s in feet), and dip (d in feet) of a span of wire—viz. $d = \frac{w \times s^2}{8t}$ (1); or $t = \frac{w \times s^2}{8d}$ (2); w for 100 lbs. copper = 0·0189 lbs., and for 40-lb. bronze wire is 0·00757 lb.

Tables of Sags and Stresses.—The following tables, giving the

relation between stress, dip, span, and temperature for the wires named, have been calculated by a formula given by Mr C. E. Lawrence in *The Telephone Magazine* for September 1901, and the figures have been found to be correct in practice. The formula is for finding the temperature required to produce any given tension when the allowable stress (in this case $\frac{1}{2\cdot5}$ of the breaking stress) at the lowest temperature (in this case 10° F.) has been decided upon. It takes the following form :—

$$t^\circ = \frac{l^2w^2}{24c}\left(\frac{1}{\mathrm{T}_1{}^2} - \frac{1}{\mathrm{T}^2}\right) + \frac{1}{\mathrm{M}wc}(\mathrm{T} - \mathrm{T}). \tag{3}$$

T = stress allowed at the minimum temperature. For 100 lbs. copper $\mathrm{T} = \frac{338}{2\cdot5} = 135$, and for 40 lbs. bronze $= \frac{200}{2\cdot5} = 80$.

T' = the stress at some higher temperature = $(10 + t^\circ)$ F.

M = the "modulus of elasticity" of the material, which is the stress in lbs. which would stretch a bar of the material 1 square inch in section to double its length, if such were possible. For H.D.C. the modulus may be taken at 17,800,000, and for bronze wire also at 17,800,000.

c = the coefficient of linear, expansion by heat per 1° F., which for H.D.C. = ·0000085, and for bronze = 0·00000887.

l = span, and w = weight of 1 foot of the wire, as given above.

In calculating the tables a series of sags is assumed, from which the corresponding tensions, T, are calculated by formulæ (2); then all the quantities on the right of formula (3) are known, and t° can be obtained.

The tensions given in the above tables are the mean values for the several spans. The tensions actually vary slightly, but the variations are so small that the figures given are near enough for practical purposes.

For wires of other sizes the sags are about the same, but the corresponding stresses will be in proportion to the weights per mile ; thus 200-lb. copper wire would have stresses about double those shown in the copper table. For different lengths of span the sags would vary nearly as the square of the length under the same conditions ; or if the sags remained the same

the stresses would be also in proportion to the square of the lengths of span.

100-LB. HARD-DRAWN COPPER WIRE

MEAN TENSION AND CORRESPONDING SAGS

Factor of Safety 2·5 at 10° F.

Spans	Temp. in ° F.	Mean Tension in lbs.	Sag in inches					
			50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	100 yds.
Winter Temps.	10	135	4·7	6·8	9·3	12·1	15·4	18·9
	20	128·0	5·0	7·2	9·8	12·8	16·2	19·9
	30	121·0	5·3	7·6	10·4	13·5	17·1	21·1
	40	114·0	5·6	8·1	11·0	14·3	18·2	22·4
Mean Temps.	50	107.5	5·9	8·5	11·6	15·2	19·3	23·7
	60	100·5	6·3	9·1	12·4	16·3	20·6	25·4
	70	94·5	6·8	9·7	13·2	17·3	21·9	27·1
High Summer Temps.	80	88·0	7·3	10·5	14·2	18·6	23·7	29·1
	90	81·5	7·9	11·3	15·4	20·1	25·4	31·4
	100	76·0	8·4	12·1	16·5	21·5	27·3	33·7

40-LB. BRONZE WIRE

MEAN TENSION AND CORRESPONDING SAGS

Factor of Safety 2·5 at 10° F.

Spans	Temp. in ° F.	Mean Tension in lbs.	Sag in inches					
			50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	100 yds.
Winter Temps.	10	80	3·2	4·6	6·3	8·2	10·4	12·8
	20	76·8	3·3	4·8	6·5	8·5	10·8	13·3
	30	73·8	3·5	5·0	6·8	8·9	11·2	13·9
	40	70·8	3·6	5·2	7·1	9·2	11·8	14·5
Mean Temps.	50	67·8	3·8	5·4	7·4	9·6	12·2	15·1
	60	64·8	3·9	5·7	7·7	10·1	12·8	15·8
	70	61·6	4·1	6·0	8·1	10·6	13·5	16·6
High Summer Temps.	80	58·5	4·4	6·3	8·6	11·2	14·2	17·5
	90	55·6	4·6	6·6	9·0	11·8	14·9	18·4
	100	52·8	4·8	7·0	9·5	12·4	15·7	19 3

Regulating.—In regulating for sag the wire is gripped in a *draw vice* (Fig. 365), and drawn up by means of the drum and

ratchet, to which is attached a length of wire called a "tail," looped round the arm on the pole. By the key lever shown the drum can be turned, thus drawing the vice nearer to the arm, and carrying the wire with it. The sag of one of the wires to be erected is regulated to the proper tension, as given in the tables supplied, by the special "dynamometer," fitted with a spring and scale like an ordinary spring balance.

Having given the proper sag to one of the wires, paying due regard to the temperature at the time, the other wires are drawn

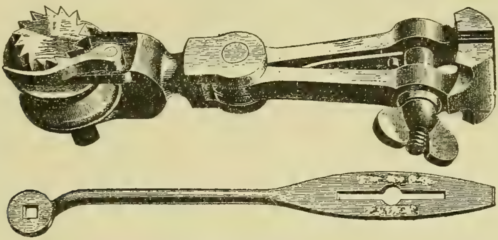


Fig. 365.—Draw Vice and Ratchet with Key Lever

up until they are parallel with the first, and the tension thus equalised.

Another convenient tool, called a "come along," is used in America for gripping the line wire. It is based on the cam principle, and has the advantage over the ordinary vice of its not being possible to nick or mark the wire, besides being much lighter in weight.

Length of Spans.—The greater the number of wires carried by a line of poles the shorter should be the distance between the poles, to give greater strength.

Snow often plays havoc with the wires under certain conditions by adhering to them until the whole becomes, perhaps, 1 or 2 inches thick, putting a great strain on the wires and the poles, especially if the wind is strong at the time.

For heavy lines of, say, 30 wires the spans should not be over 50 yards, but may reach 80 yards for light lines.

The height of poles should be arranged so that the lowest wires will not be less than 20 feet from the ground, and over public roads not less than 25 or 30 feet.

When taller poles have to be used at special points of a route, the poles on each side should be so graded in height as to gradually raise the height of the line, for the sake of appearance, and to lessen the stress on the higher poles.

Heavy lines, even on straight routes, should be stayed at every few poles, to give lateral strength to resist wind pressure.

TRANSPOSITION OF LINES

Twist System.—Since the use of metallic circuit lines has become general, nearly all lines in this country have been run on what is called the *twist* system, for the prevention of *cross-talk* and inductive noises. In this system, the two wires of a line are continuously twisted about each other, so that each wire may be equidistant from any outside source of induction. With such construction the induced currents in the two wires, due to the magnetic induction of electric currents, being in the same direction in the two loop wires, will meet and neutralise each other at the two ends of the line, so long as the resistances, leakages, capacities, and inductances of the two loop wires are equal. If they are unequal in respect of any of the qualities

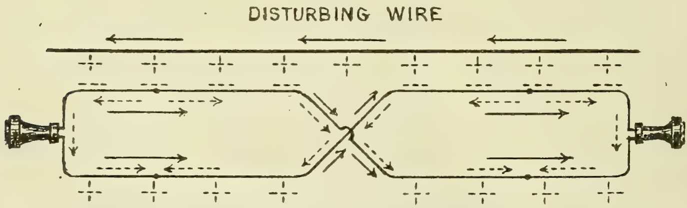


Fig. 366.—Diagram showing Induced Effects on Wires

mentioned, the neutralisation of the induced currents is not effected at the instruments, and more or less induction is heard.

As first pointed out in 1889 by Mr J. J. Carty of New York, the inductive effects of the statical charges in lines are much more serious than those due to electro-magnetic currents. In fact, he found that the latter may in most cases be neglected,

whilst the effect of the induced-capacity charges, causing surgings of electricity backwards and forwards in the lines, gave rise to all the inductive troubles in telephone lines, and could not be altogether eliminated.

This is illustrated in Fig. 366, in which the starting of a current through the single disturbing line, as shown by the full

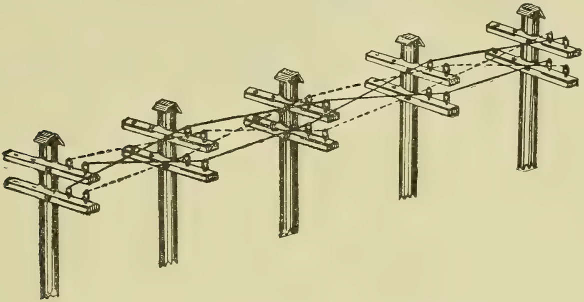


Fig. 367.—Four Wires run on Twist System

arrows, causes currents in the crossed loop, also shown by full arrows, these meeting and neutralising in the receivers, whilst the changes in the static charges in the disturbing line cause movements of electricity in the loop wires, as shown by the dotted arrows. The latter meet and neutralise each other about the positions of the dots, and affect the receivers in their movements.

Except under exceptional circumstances, the effects may,

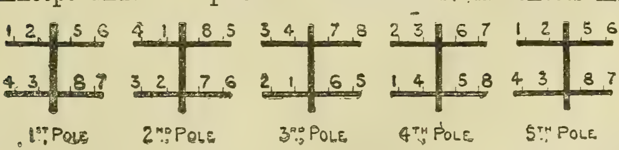


Fig. 368.—Diagram of Positions of Wires for Twist System

however, be sufficiently reduced by the " cross " and " twist " systems as to be negligible, if the loop lines are balanced as regards inductance, capacity, etc.

Figs. 367 and 368 show how the twist system is carried out in practice. The wires are usually run in sets of four, as shown, two 4-wire arms being used on each pole. It will be observed

that the wires change their position on each pole—each of the numbers of Fig. 368 representing the position of a corresponding wire. Each wire revolves a quarter turn between every two poles, so that at the first and fifth poles the positions are the same, a complete rotation being made between them. Wires No. 1, 2, 3, and 4 form one set, and 5, 6, 7, and 8 another set, the different loops being arranged diagonally as 1 and 3, 2 and 4, 5 and 7, and 6 and 8.

The twist system is, undoubtedly, the most effective method of getting rid of inductive interferences on open lines, but there are certain drawbacks in connection with it. Wires run as described are more liable to faults, especially contacts, when running other wires, and much more difficulty is experienced in tracing the faults, as it is not easy for the linesmen when walking along the route to see when lines are in contact, as even when the wires are in good order they appear to cross each other. The wires are also more difficult to regulate, and from a distance always look as though they were out of regulation.

"Transposing" or "Cross" System.—This is another method of running loop wires so as to keep them equidistant from outside sources of electrical disturbance. By this method the wires are run straight and parallel, as ordinary telegraph lines, but their positions are reversed at certain points, so that the left-hand wire goes to the right, and *vice versâ*. The number of crossings having to be such as to keep both wires (taking their whole length) the same average distance from other lines running near. This method has not been much used in this country, but the plan is generally followed on the Continent and in America. The wires run straight on the poles, just as ordinary single lines; but at certain points the wires are terminated on double arms and insulators, or on double brackets and insulators. Another method of transposition as adopted in America is shown by Fig. 369. The wires, it will be seen, are terminated one at the top and the other at the bottom of a special "transposition" insulator.

The points of transposition of the different loops must vary,

and diagrams are drawn for the use of the workmen showing the points of crossing for the loops on the different arms. Fig. 370 shows such a diagram for a 12-wire route of two 6-wire arms, the dotted lines crossing the loops showing the positions

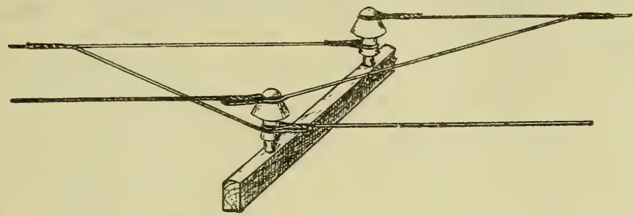


Fig. 369.—Method of Transposition

of the special transposition poles. The letters shown against the dotted lines are used for locating purposes. In the Standard system of the Bell Telephone Companies in America the distance between such special poles is given as 1300 feet, or nearly $\frac{1}{4}$ mile, this being the shortest distance between any

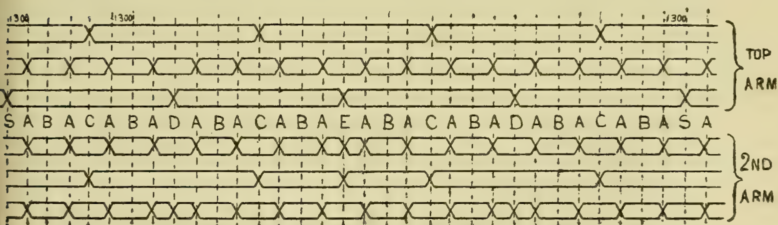


Fig. 370.—Transposition Diagram for 12-Wire Route

of the crossings. The longest distances between crossings as shown on the third loop from the top is 8 times $1300 = 10{,}400$ feet, or nearly 2 miles.

The above gives the shortest distance of what is equivalent to a complete rotation, as $1300 \times 2 = 2600$ feet, or two turns per mile, and the longest length as 4 miles per turn, whilst with the twist system, the average of a rotation is about $4 \times 65 \times 3 = 780$ feet, or about seven turns per mile. As the cross

system seems quite effective, it would appear that there are more turns than are really necessary with the twist system.

Stresses on Poles, etc.—These stresses are due to (1) the weights which they support in the shape of wires, arms, insulators, etc., the vertical components of the stresses of the stay wires. These constitute the normal vertical or crushing stresses, which may be enormously augmented during so-called "telegraphic" snowstorms by the great weight of snow and ice, which may adhere to the wires until a diameter of as much as 2 or even 3 inches may be reached. The transverse stresses on poles are due to (2) the pull of the wires, which in the case of terminal poles, or poles set on a curve, may be very great, and must, where possible, be counteracted by stays or struts. Wind pressure (3) on the surface of the wires and poles exerts a very heavy transverse stress on the poles, in times of storm rising to as much as 20 lbs. per square foot of surface * in exposed positions in this country. In calculating the effective surface of wires and other round objects, two thirds the diameter multiplied by the length is taken. When the diameter of the wires has been increased by snowstorms, as mentioned above, and then a wind-storm arises, the stresses are such that, in extreme cases, no reasonable strength of construction can withstand them and some part of the structure must give way; this should preferably be the wires, as these are easiest to replace, and would in any case have to be re-erected if any other part should break down.

The stresses on a terminal pole may be shown graphically by constructing a triangle of forces. Let R, Fig. 371, be the point where a stay wire is attached, and also where the resultant force due to the pull of all the wires may be supposed to act; R S represents the stay wire at an angle of A° with the vertical pole and at an angle of B° with a horizontal line. Draw F′ in opposite direction to R F, and of such a length that it represents the resultant force on some convenient scale, draw a vertical line, F′ C, to cut R S, then the length of R C on the scale taken will

* The B.P.O. has adopted 17 lbs. per sq. ft. as standard maximum pressure.

represent the stress on the stay, and the length of F′ C the vertical pressure on the pole. For a strut fixed at the same height and angle the stress would be the same, but would be in the nature of a pressure, the wire stress being exerted in the opposite direction.

The sides of the triangle P R S, formed by the pole, the stay and the ground line, are proportioned to those of the triangle F′ C R, and can, therefore, be used to determine the stresses, so that if any two of the lengths R P, P S, and R S are known, and any one of the stresses such as F, the other stresses can be readily found by proportion, as the stresses are proportional to the sides to which they are parallel. For example, suppose R P = 20 feet, P S = 10 feet, and the resultant stress of, say, twenty wires, each pulling 100 lbs., is 2000 lbs., acting at the point R. R P S being a right-angled triangle, the length of R S will be $= \sqrt{20^2+10^2} = \sqrt{500} = 22{\cdot}4$ feet, and the stress on the stay R S $= 2000 \times \frac{22{\cdot}4}{10} = 4480$ lbs., and the vertical pressure on the pole R P $= 2000 \times \frac{20}{10} = 4000$ lbs.

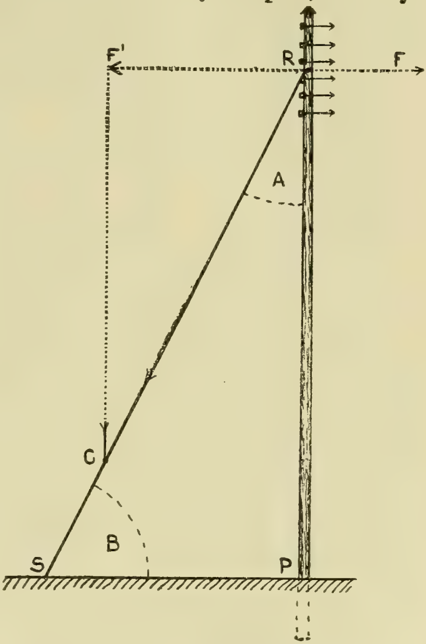


Fig. 371.—Diagram of Stresses on Poles and Stays

In trigonometrical language the stress on the stay is equal to the resultant force F, divided by the sine of the angle A or

$S = \frac{F}{\sin A} = \frac{F}{\frac{SP}{SR}}$; the stress is also equal to F divided by the cosine of the angle B, which is also $= \frac{F}{\frac{SP}{RS}}$. This in the example given above would be $= \frac{2000}{\frac{10}{22 \cdot 4}} = 2000 \times 2{\cdot}24 = 4480$ as before.

The pressure on the pole $= \frac{F}{\text{tangent } A} = F \times \text{cotangent } A = R \times \frac{RP}{SP}$.

The figures given in the table (taken from B.P.O. Instructions) are intended to simplify the practical calculations of these stresses, as only the height of the pole R P and the "spread" of the stay S P (which are both easy to measure) are required. The figures in the first column are found by dividing the height of the pole by the "spread" of the stay, and are thus the cotangents of the angle A. These figures multiplied by the total tension of the wires F give the downward pressure on the pole. The figures in the second column give the reciprocal of the sizes of the angles corresponding to the cotangents in the first column and these multiplied by F give $\frac{F}{\sin A}$, which is the tension on the stay wires. Taking the example given before, $\frac{RP}{SP} = \frac{20}{10} = 2$. This multiplied by 2000 gives 4000 lbs. the pressure on the pole. The corresponding figure in column 2 is 2·24, and this multiplied by 2000 gives 4480 lbs. tension on the stay as before.

Mr A. P. Trotter, the Electrical Adviser to the Board of Trade, has stated that if poles are designed to withstand the maximum side pressure of the wind (17 lbs. per sq. ft.) on the poles and wires which they carry, the stress due to the weight of the wires may be neglected.

The factor of safety for poles is generally taken at about 8 when designing.

Wires at an Angle.—When the wires on the two sides of a

CO-EFFICIENTS FOR CALCULATING STRESS

$\frac{\text{Height R P}}{\text{Distance P S}}$ Multiplier for Pressure on Pole	Multiplier for Stress on Stay	$\frac{\text{Height R P}}{\text{Distance P S}}$ Multiplier for Pressure on Pole	Multiplier for Stress on Stay
8·	8·07	4·	4·12
7·5	7·57	3·5	3·64
7·	7·07	3·	3·16
6·5	6·58	2·5	2·70
6·	6·018	2·	2·24
5·5	5·59	1·5	1·80
5·	5·10	1·	1·41
4·5	4·61		

Multiply pull of wires by above numbers

pole do not run straight through, but go off at an angle, a transverse or bending stress is thrown on the pole which requires to be taken up by one or more stay wires. The bending stress is greater the larger the deflection of the wires from a straight line, or the less the angle the wires on the two sides of the pole make with each other.

Let P in Fig. 372 represent a pole, and P A and P B the directions of the wires. Then if the pulls on the two sides are unequal, take P S on some scale, equal to the total stress on the right, and P S′ equal to the stress on the left, of the pole. Form the parallelogram P S R S′, and draw its diagonal P R, which will represent in force and direction the resultant force of the pull of the wires. This resultant can be counteracted by a single stay wire in the opposite direction, P R′, which may be calculated as for a terminal pole on which the wires pull with a stress equal to, and in the direction of, P R. An even better method of counteracting the pull on the pole when the angle is nearly a

right angle is to use two stays in line with the directions of the two wires, as shown by the dotted lines in Fig. 372.

If the stresses on both sides of the pole are equal, the re-

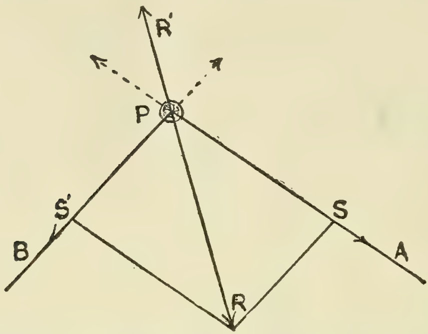


Fig. 372.—Diagram of Stresses on Angle Pole

sultant, P R, will divide the angle, B P A, into two halves, and calculation will be easy, as all the sides will be equal, and right-angled triangles can be formed by drawing the other diagonal from S to S′

CHAPTER XXV

UNDERGROUND WORK

The invention and improvement of dry-core cables and the general adoption of metallic circuit lines has rendered the use of underground lines perfectly feasible and cheap, and has led to a great extension in their use. It seems only a matter of a short time before all telephone lines in towns will be run underground, with the exception of the short lengths needed for distribution, and even these will be dispensed with in some towns.

In most cases the cost of installing such underground lines is higher than that of overhead lines when the number running in any one direction does not exceed about 100; but for more than this number the cost is less, and for large systems considerably less. With regard to the cost of maintenance, there is no doubt that a good system of underground work is much more economical.

Cables.—The form of cable used for underground work is now invariably that known as *dry-core*, so called because it depends principally for its efficiency upon the presence of dry air between the wires, instead of the wires being insulated by paper or cotton impregnated with resinous oil, which was the system employed before the introduction of the dry air and paper insulation. The following are the principal points in the specification of the cables most commonly used. Each conductor to be of the highest conductivity copper wire of a minimum diameter of 24·5 mils, to be continuously insulated with manilla paper with overlap; if laid on longitudinally this is to be kept in position by a single cotton thread. The paper must be uniform in texture and thickness, and a 1-inch strip

must support a weight of 4 lbs. per mil of its thickness. Pairs of the wires are to be twisted together in a right or left handed direction or "*lay*" as it is called, of 4-inch pitch for cables up to 50 pairs, and of 6-inch for cables above that size. The pairs are then made up into cables of various sizes up to 600 pairs, in several layers, which are alternately twisted in opposite directions. To identify the wires in the pairs, the covering of one is coloured, and the other white; and to identify the pairs, two adjoining pairs in each layer have distinguishing colours. The whole is to be covered with two layers of paper, and finally covered with a metal tube, composed of an alloy of 97 per cent. lead and 3 per cent. tin. For cables of the largest size the tube is to be 125 mils in thickness, and of a maximum diameter of $2\frac{5}{8}$ inches. The mean mutual capacity of the wires is not to exceed ·07 microfarad per mile of circuit, the insulation resistance is to be not less than 1000 megohms per mile, and the conductivity resistance not more than 88 ohms at 60° F.

The above cable is known as 10 lbs. cable, as that is the weight per mile of a single conductor. Similar cables of 20 lbs. conductors are also extensively used, the electrical qualifications per mile being (*a*) maximum conductor resistance 44 ohms; (*b*) mutual capacity ·07; (*c*) insulation resistance 1000 megohms; all at 60° F. In special circumstances cables of 40, 70, 100, 150 and even 200 lbs. conductors are used.

The 10 and 20 lbs. cable of various sizes as shown in table on page 361 are used for overhead work.

Several makes of cables conforming to the same general conditions are made, these differing only in the methods adopted in order to get a continuous loose wrapping of paper on the wires, and so give as great an air space as possible between the wires and thus obtain low capacity.

The alloy of lead and tin is used because it is stronger than lead alone, and also better resists chemical action, such as that of creosote; it is also cheaper for the same strength.

The Quadruple Pair Cable.—A method of laying up the pairs of wires in a dry-core cable which differs from that described above is used by the British Post Office, and for which

it is claimed that it has more freedom from inductive troubles and more adaptability in the way of being able to combine two or more pairs to form a line of higher conductivity when such is required, and also that such cables are more suitable for the building up of superimposed circuits.

The cable is known as the Martin-Dieselhorst cable and is made by Siemen Brothers. In it the two wires of a pair are twisted together as usual, but instead of the pairs being laid up in layers in sets of four, pairs are twisted together as shown in section in Fig. 373, which shows four sets of four pairs made up into more or less circular form with five other odd pairs filling up the intervening spaces, the four outer pairs of these latter forming another quadruple set of pairs.

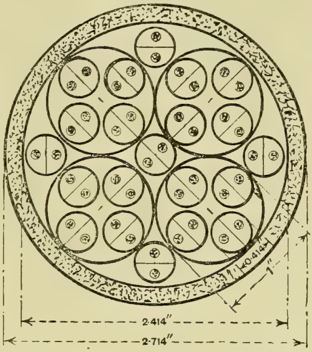


Fig. 373.—Section of Quadruplex Pair Cable

In combining the pairs to form larger conductors or for the purpose of use as superimposing circuits the diagonal pairs of any quadruple set are always taken together.

Except where superimposing work is of much importance the cable does not appear to have advantages over the ordinary form, as space is certainly lost by the arrangement and it is not possible to get as many pairs of a certain size in the same diameter of cable with the same minimum of capacity.

Dry-Air Pumping.—As it is not always possible to prevent the access of damp air into the body of a dry-air cable when jointing, etc., arrangements are made so that air, specially dried by passing it through cylinders containing chloride of calcium, may be pumped through the cable when the insulation falls. For this purpose small nozzles are tapped through the lead covering at several points, but generally near joints. To one of these nozzles an air pump is attached by flexible tubes, the nozzle at the distant end being opened so that the damp air

may be displaced by dry air pumped in until the full insulation resistance is restored. It is, of course, necessary to prevent the ingress of damp air into the cable as much as possible by choosing dry days for the jointing, completing it as quickly as is practicable, and on damp days keeping the ends of the cable sealed up with an india-rubber or lead cap; or, if the work must be carried on, it should be done in an enclosed space in which a fire is kept burning.

Conduits.—These are receptacles for the cables, and must be laid at least 18 inches below the surface of the roadway. There are numerous types of such conduits, but they all amount to some method of forming cylindrical holes in the ground of sufficient size (3 inches) to allow the cable to be drawn into or out of them when required. This is found to be a much better plan than that of strengthening the outside of the cable by wire armour, and then laying it directly in trenches made in the ground, since it allows of the cable being drawn out for examination or replacement, and protects it from excessive pressure due to ground subsidences, etc.

In this country three principal kinds of conduits are used for telephone cables :

(1) Cast-iron socket and spigot pipes.

(2) Multitubular cement conduits.

(3) Glazed earthenware ducts.

Cast-Iron Ducts.—These are extensively used, and are of the shape shown on the right of Fig. 374, each pipe being 9 feet 4½ inches in length (including the socket), 3 inches internal diameter, and each weighing about 100 lbs. The interior surface must be smooth and regular, so as not to damage the cable when being drawn in, and for the same reason the inside edge of the spigot end is carefully rounded.

Jointing.—The pipes are fitted and the joint partly packed with yarn, and then, with the assistance of a mould of soft clay, melted lead is run into the joint, and, when cold, hammered or "caulked," so as to render the joint solid and watertight.

Draw Wire.—As the jointing progresses, a No. 8 iron wire

is drawn through the tube, or " duct " as it is called, by means of which, when completed, the hauling rope is pulled through, ready for drawing in the cable.

To test if the pipes are correct, a mandril of iron covered

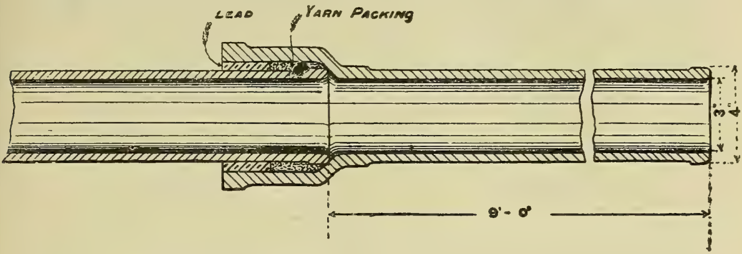


Fig. 374.—Joint in Cast-Iron Ducts (Scale $\frac{1}{8}$)

with lead $2\frac{3}{4}$ inches diameter and 4 feet long must be drawn through the duct, and each is required to hold an air pressure of 5 lbs. per square inch for 30 minutes when closed at the ends.

Split Pipes.—These are used when only one or two ducts are being laid and joints are required to be made, or the direc-

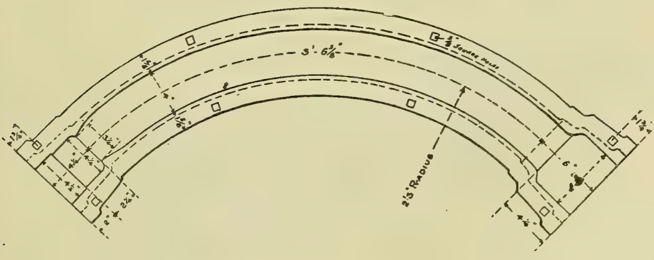


Fig. 375.—Right-Angle Split Pipe

tion of the ducts altered. They are pipes made in two halves longitudinally, fitted together to form one pipe by means of square pins passed through holes in flanges formed on the edges, as shown in Fig. 375 ; the joints are clamped by tapered cotters passing through slots in the pins, as shown in Figs. 376 and 377, the former of which is a transverse section through

the complete pipe. Fig. 378 shows a straight form of split pipe, and also shows how it is connected to other pipes, a bell-mouth pipe being used on one side. Tow packing and red lead are used to render the joint waterproof.

The bell-mouthed pipe is enlarged to 4 inches internal diameter at the bell end; this is to allow of the lead sleeve

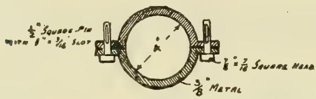


Fig. 376

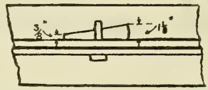


Fig. 377

Joints in Split Pipes

which is used for jointing being slipped back over the cable into the pipe whilst the wires are being jointed.

Concrete-Block Conduits.—When more than one duct is required concrete blocks, in which a number of ducts have been formed, are used by the National Telephone Co. It is considered that these occupy less space, are equally efficient, and cost less, than a corresponding number of iron ducts.

The blocks are made in nine sizes, for 3, 6, 9, 12, 16, 20, 25

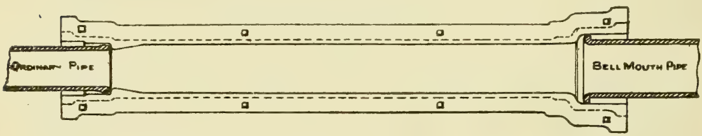


Fig. 378.—Straight Split Pipe (Scale $\frac{1}{16}$)

30, and 36 ducts. They are all made 1 metre (3 feet $3\frac{3}{8}$ inches) in length. Fig. 379 gives the end view of a block for 9 ducts. On the top and two sides recesses will be noticed; these extend the full length of each block, and are for the reception of (usually) square iron rods, which are used to strengthen the blocks, and also to ensure their being in line, so that the whole shall fit properly together. Besides these rods, the ends of all blocks but the 3-duct size are, when laid, supported on con-

crete "bearers" firmly bedded in the earth. Fig. 380 shows a 3-duct block complete.

Laying.—The blocks are laid so as to leave a space of $\frac{3}{8}$ths of

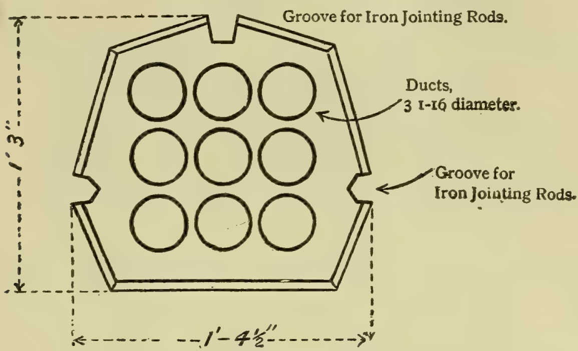


Fig. 379.—End View of 9-Duct Concrete Conduit Block

an inch between the ends, to allow of dirt, etc., falling through. The iron bars are put in the grooves, care being taken that not more than two bars meet on the same blocks. The bars must

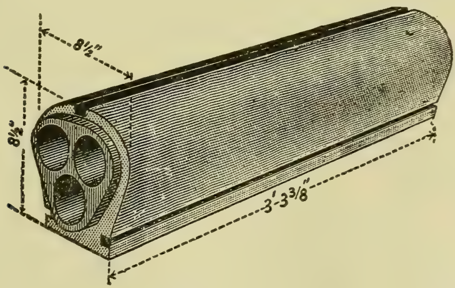


Fig. 380.—3-Duct Concrete-Block Conduit

then be well covered with cement. A strip of canvas coated with asphalt is passed right round the joint under the blocks to close up the space, and the recesses left for this purpose are

afterwards closed up with cement, as shown in Fig. 381. To ensure that the ducts are properly in line, a lead mandril 4 feet long and $2\frac{7}{8}$ inches is passed through.

The ends of unused ducts should be kept plugged up.

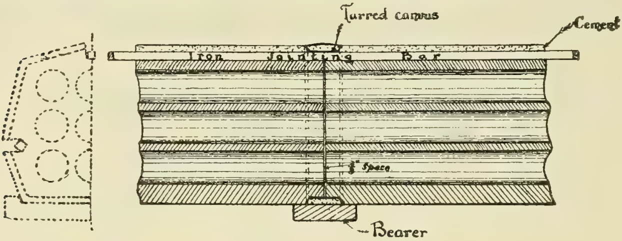


Fig. 381.—Method of making Joint in Concrete-Block Conduits

When stored, the concrete blocks should be kept moist, as they are apt to crumble away when left dry.

Glazed Earthenware Ducts.—These have been used very extensively in the London district by the British Post Office authorities. Fig. 382 shows half an end view and half a section of one of the pipes, which are single ducts having a $3\frac{1}{2}$-inch bore, with the ends well rounded. They are made of an octagonal outside section, and in two lengths of 18 inches and 24 inches, the latter one being only used for connecting the ducts into the manholes.

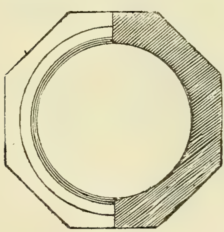


Fig. 382.—Glazed Earthenware Duct

Laying.—A foundation is first made by laying a bed of concrete at the bottom of the excavated trench, this bed being stiffened and strengthened by lengths of T section iron embedded in the concrete.

The 18-inch lengths of ducts are then laid over the foundation end to end, and completely enveloped in mortar cement, and to prevent the mortar getting into the pipes the joints are closely covered with a wrapping of waterproofed calico.

This form of duct has the advantage of greater flexibility

over both the concrete and cast-iron conduits, as the short lengths used allow of slight curves being negotiated to avoid various obstructions met with. It has also the advantage over concrete conduits of being practically gas and water proof. It is, however, considerably more expensive than the concrete-block conduit, when several ducts are required. Fig. 383 shows a section through 30 ducts. The practice in the Post Office

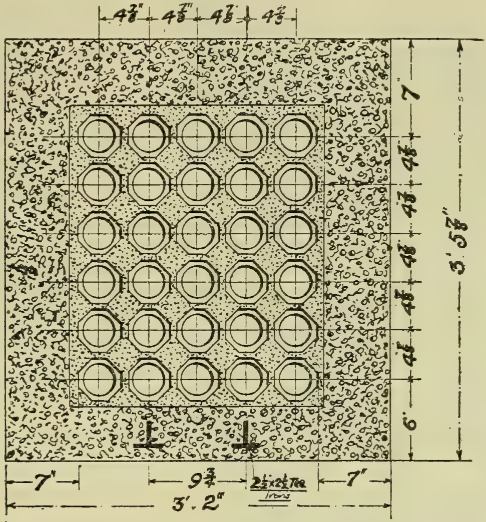


Fig. 383.—Method of laying Earthenware Ducts

is to use cast-iron pipes where only 5 ducts or under are required and earthenware ducts for more than that number, as this is found to be the economic dividing line.

American Practice.—In America wooden ducts of various kinds are much used, the wood being protected from decay by creosoting or by tar asphalt. One kind, known as the "box" conduit, is made up in the form of a series of troughs, like endless pigeon-holes of square section. Another kind is made of single tubes of either round or square external section, and called "pump-log" ducts. The "Valentine" conduit is

made up of wooden blocks with several semicircular grooves. These blocks fit one over the other, and form a number of circular ducts, as shown in Fig. 384. Ducts made of compressed wood pulp or paper coated with asphalt are also used.

All the above ducts are, when laid, embedded in concrete.

Cement-lined ducts are also much used, formed of a thin wrought - iron tube having a lining of hydraulic cement.

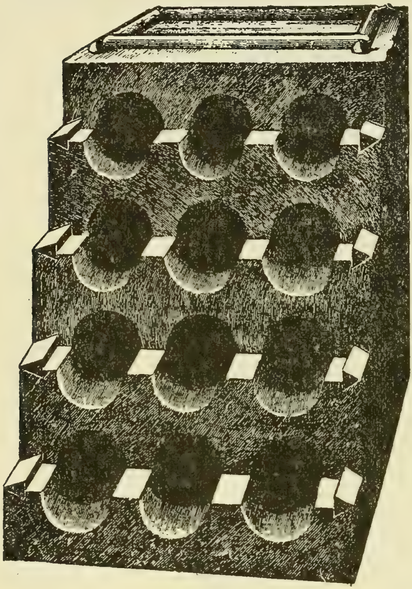


Fig. 384.—" Valentine " Wood-Block Conduits

Cement-block conduits and glazed earthenware ducts, somewhat similar to those used in this country, are also used. The latter are called " vitrified clay " or " hollow brick " ducts.

Manholes. — When more than two ducts are to be laid it is necessary to provide underground chambers called *manholes* for the accommodation of the workmen in drawing in, jointing, splicing, etc. These vary in size from $3\frac{1}{2}$ feet in length, $2\frac{1}{2}$ feet in breadth and 3 feet in depth to $6\frac{1}{2}' \times 5' \times 6'$ respectively. Fig. 385 gives a sectional elevation of one of the smallest size under a footway, and shows the general method of construction, Fig. 386 being a plan of the same. The waterproof brickwork (Staffordshire Brindle bricks) is bedded on a 6-inch foundation of concrete, cemented at top and sloped for drainage to a 2-foot length of 12-inch (inside diameter) earthenware pipe, to which the leakage water drains, the pipe

being embedded in concrete.* The brickwork is 9 inches

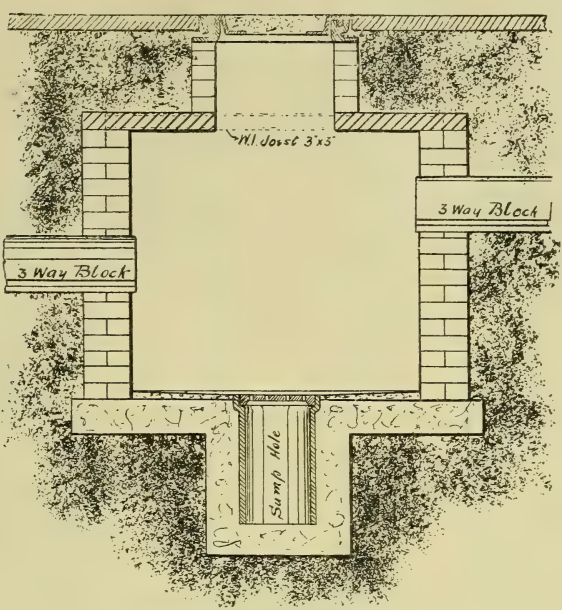


Fig. 385.—Scale $\frac{1}{36}$

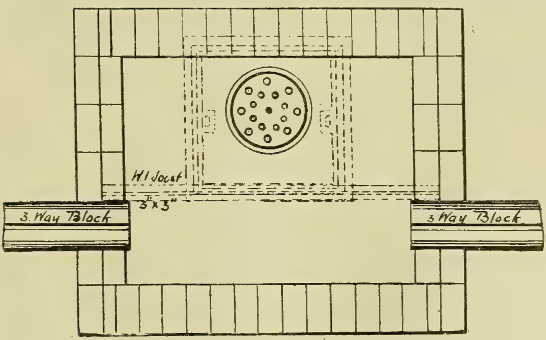


Fig. 386.—Manhole under Footpath

* In the latest practice the bottom end only of the pipe is stopped up with three inches of concrete.

thick for the small, and 14 inches thick for the large manholes under roadways, as shown in Figs. 387 and 388.

The roof is strengthened and supported by two rolled steel joists, each 3 inches deep by 3 inches wide, laid on stone blocks resting on the brickwork. The roof itself is formed by large

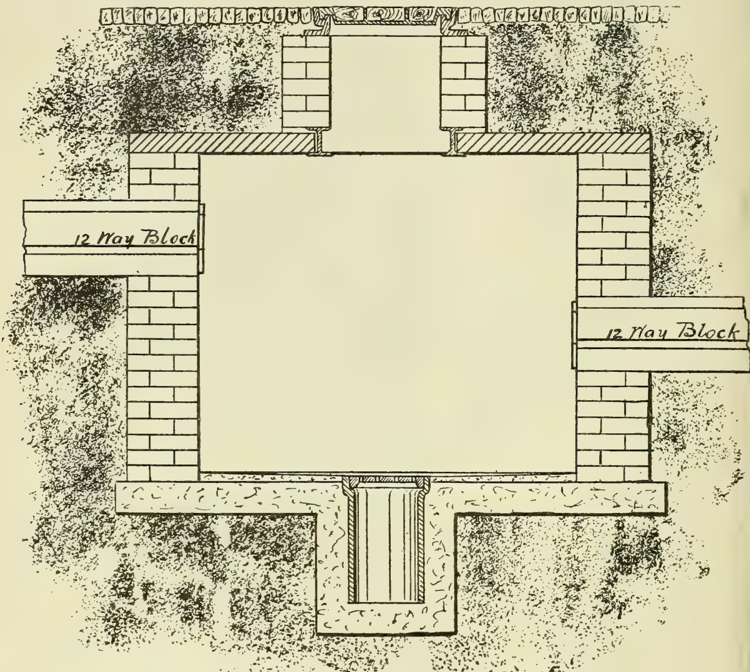


Fig. 387.—Manhole under Roadway (Scale $\frac{1}{36}$)

York stone blocks resting on the joists and brickwork and the manhole cover frame is fitted on top of these as shown, the whole being rendered watertight by cement. If formed under a roadway heavier joists, 5 inches by $4\frac{1}{2}$ inches, should be used, as shown in Figs. 387 and 388. The ducts, if of iron, are terminated in the manholes by well-rounded bell-mouthed ends, so that the cables may not be injured by sharp edges.

The top part of the cover is filled in to the level of the road with hard wood blocks (such as jarrah wood) or with other material to conform with the general construction.

Obstructions.—In laying the pipes and making the manholes obstructions are frequently met with, owing to the existence of gas, water, and other mains, and much engineering skill has to be exercised in order to avoid such obstructions. Figs. 389 and 390 show an example of this, a double manhole having to be constructed in order to drop from a 4-foot level in one street to a lower level in another street at right angles,

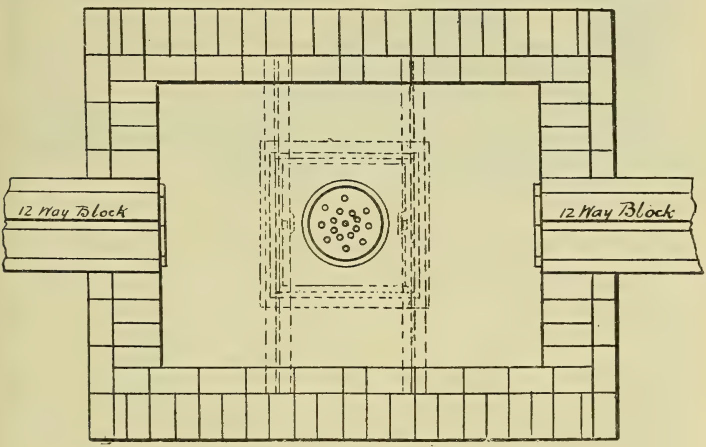


Fig. 388.—Plan of Manhole under Roadway (Scale $\frac{1}{36}$)

so as to avoid obstructions in the shape of gas, water, and hydraulic mains.

Concrete-Moulded Manholes.—The standard practice in America is to make the manholes of concrete moulded in position by the help of temporary wooden templates or moulds. The form generally given to them is egg-shaped in plan, with flattened ends where the ducts terminate, this shape being adopted for greater strength to resist side pressures, and also for cheapness of construction. The walls are moulded 8 inches thick, and the roof is arched over.

Concrete-Block Manholes.—Another method of manhole

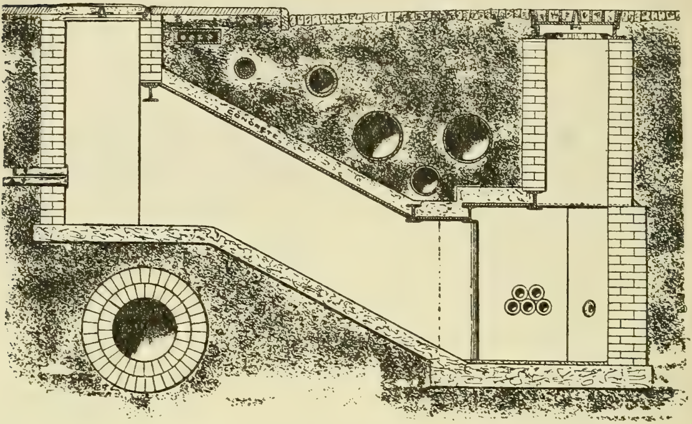


Fig. 389.—Section of Double Manhole (Scale $\frac{1}{74}$)

building which has found a good deal of favour in America is to use large concrete blocks, moulded in five different shapes

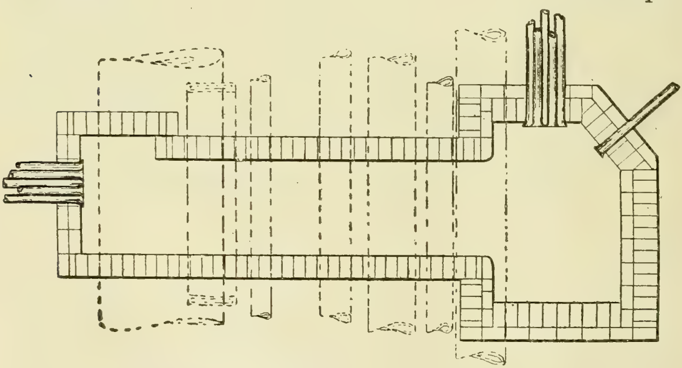


Fig. 390.—Sectional Plan of Double Manhole (Scale $\frac{1}{74}$)

suitable for the formation of manholes of a similar egg-shape. This is found to be a cheaper and more rapid method of building than that of direct moulding on the spot.

For access to manholes iron steps are built into the walls under the covers.

Position of Manholes.—Manholes should be constructed at points where the cables branch or change direction, preferably at the corners of streets. The distance between them on a straight run should be about 150 yards. A double curve should not be allowed between any two manholes.

Drawing in the Cables.—To enable cables to be drawn into ducts, a chain or manilla rope is first drawn through by means of the steel wire left in the duct for that purpose. Advantage is taken of this operation to give a final cleaning to the duct by drawing through a cylindrical brush, followed by a waste

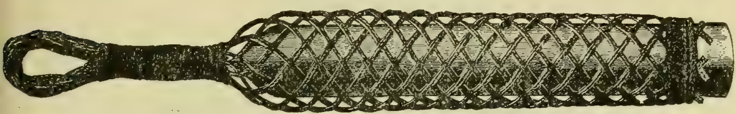


Fig. 391.—End Cable Clip

length of cable, covered with a coating of tallow, to which any loose dirt adheres.

To attach the rope or chain to the cable the "cable clip," shown in Fig. 391, is used, this being an open cylindrical cage made of galvanised steel wires plaited together. The wires at one end are all gathered together, passed round a thimble, and firmly bound. The thimble is not shown in the figure.

The lead covering of the cable end having first been beaten down on to the wires to give a firm support, the clip is slipped on to the cable, and its open end bound down by four or five turns of binding wire. The draw rope or chain is then attached, with a swivel interposed, and when tension is put on the clip it lengthens and at the same time contracts in diameter, causing it to firmly grip the cable.

If the cable is a small one it may be drawn through by men without any mechanism, but if large it is necessary to provide a winch, such as shown in Figs. 392 and 393, which

also show an arrangement of frame and pulleys, by which the cable is guided, and damage from sharp bending, etc., prevented. These pulleys should be used at both ends.

These figures also show another method of roofing a small

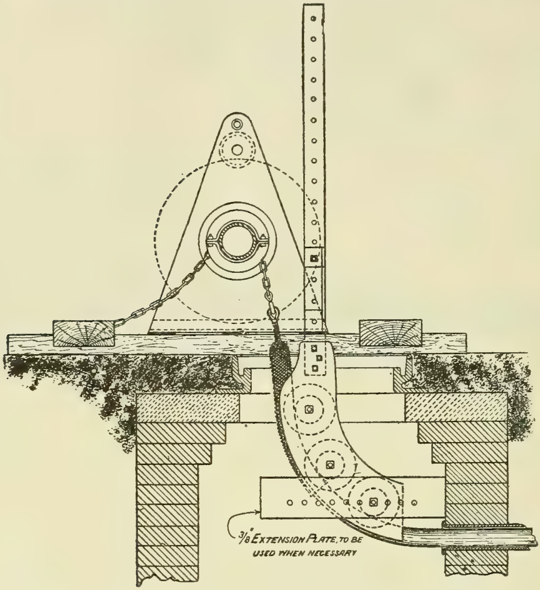


Fig. 392.—Winch and Cable Guide, Side View (Scale $\frac{1}{28}$)

manhole without employing joists, a large York stone being employed instead.

The cable is supplied on large wooden drums, which are fitted on axles, so that they may revolve as the cable is drawn off.

As the cable passes into the duct it is covered with a coating of petroleum jelly for lubrication, so as to prevent damage by friction ; this is in place of the tallow or soft-soap composition that was formerly used.

Another form of wire clip is shown in Fig. 394. This is

open at both ends, and is furnished with a double "tail" for drawing. It is useful for slipping back over the cable, so that a longer length of the front end can be drawn through in a restricted space.

Cable Jointing.—Prior to the jointing of the wires a lead

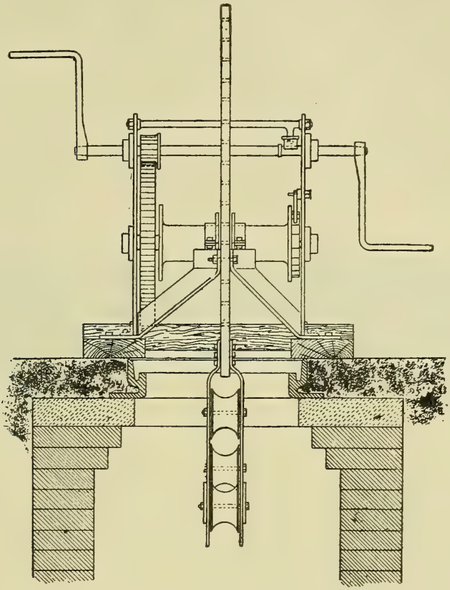


Fig. 393.—Winch and Cable Guide, End View

sleeve, with dry-air plug wiped into it, should be slipped over the end of one of the cables, and into the bell-mouthed pipes, to be afterwards drawn forward so as to cover the whole cable joint.

A thoroughly dried paper sleeve must first be drawn over the paper covering of one of the wires to be jointed. The ends of the wires to be connected are then tightly and evenly twisted together for a length of $\frac{3}{4}$ of an inch, at right angles to their length, and the twist bent back parallel thereto, great care being

taken that the wire is not nicked by the pliers. The twist is not to be soldered. Care should be taken to see that the paper covering on both sides is taken up with the first twist of the copper, and that the paper sleeve is slipped back, so as to completely cover the twist. Great care must be taken to maintain the twist of each pair throughout the joint. The wire joints should not all come together, but should be spaced so as to keep the diameter of the whole splice as small as possible.

After all the wires are jointed the whole is to be wrapped round with one lapping of $1\frac{1}{2}$-inch white tape, laid on without any overlap between the turns. One and the same pair of wires in each cable is to be brought out at each joint through

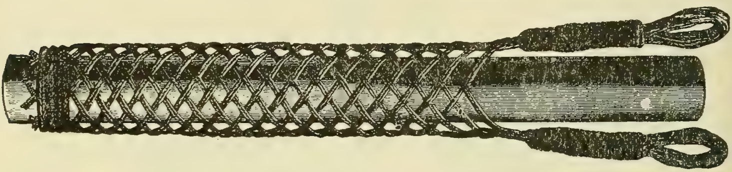


Fig. 394.—Open Form of Cable Clip

the dry-air plug with well-dried switch-board wire properly insulated and jointed together, and then coiled up in the plug. This is to be used as a simple means of locating any general fault that may develop.

A plumber's wiped joint must next be made between the ends of the sleeve and the lead covering of the cable, as shown in Fig. 395, the left-hand side of which is partly in section.

Pothead Joints.—As paper-covered wires are not suitable for use outside the cable, and as the inside of the cable must be sealed to prevent access of damp air, it is usual * to join rubber-covered wires on to the paper-covered wires, and seal the cable at the point of junction by what is called a "pothead" joint. This is made as follows :—A lead sleeve about one and a half times the diameter of the cable, of a length about twelve times the diameter of the cable, and fitted with an air nozzle, is slipped over the end. The lead sheathing having been stripped

* Except where a cable-head box is used.

off for a sufficient distance, the wires are jointed and soldered to the rubber-covered wires, and paper sleeves, previously threaded over the wires, are drawn over the joints. The latter should be made at different lengths, so that they are evenly distributed, as with the ordinary splice. The lead sleeve is then drawn forward to cover the joint, and the bottom part is thoroughly packed with cotton wool until it is a little higher than the position of the nozzle. A wiped joint is made at the bottom of the sleeve on to the cable, and a special insulating composition is melted and poured into the sleeve, so as to penetrate between the wires and thoroughly seal up every part. The composition is made up of about 12 parts palm pitch, 4 of ozokerite, and 1 of Stockholm tar.

If the joint is made inside a building it is now complete,

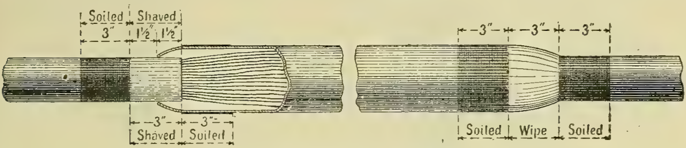


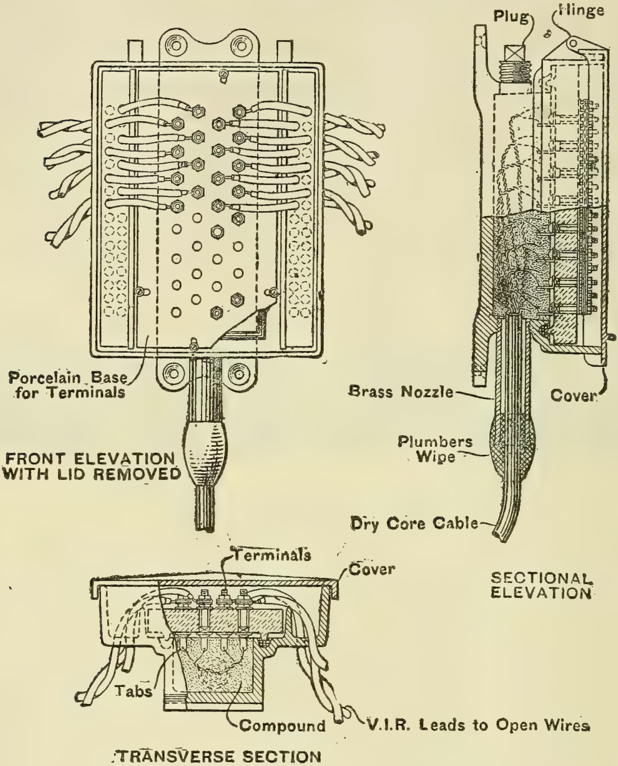
Fig. 395.—Wiped Joints

the rubber wires being carried to the proper terminals, but if in an exposed situation, it is necessary to further protect the open end. This is done by bending down the rubber wires over the edge of the sleeve, and then fitting over them a lead cap as shown at the top of Fig. 399. The wires and the open end of cap are bound round with ozokerite tape for better protection. As shown in the figure, the pothead is fixed at the top of a distributing pole, which is the best position for terminating. A branch cable, with joint, is also shown connected to the pothead for distributing purposes.

To ensure the penetration of the composition between the wires, use is made of air compressed to about 20 to 25 lbs. per square inch, a special machine being employed for this purpose.

Cable Heads.—Whilst the pothead joint is a very satisfactory and economical method of terminating a dry-core cable where the wires do not need to be disturbed it is not a sufficiently

flexible method of terminating where it is necessary at times to alter the connections of the wires as with covered wire distributing, so that it is now usual to terminate cables for such a purpose



Figs. 396, 397, and 398. Terminal Box
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on a cable-head or " terminal box " of the form shown in Figs. 396, 397, and 398. It consists of a cast-iron box with cast-iron lid hinged at the top so that it can be lifted entirely out of the way. A thick porcelain block is screwed into a recess with a packing so as to form a closed chamber except for an opening at the bottom fitted with a brass nozzle through which the cable passes and is rendered airtight by a plumber's joint.

The porcelain block is perforated for screw terminals at the

front and soldering tabs at the back to which the paper-covered cable wires are soldered before the block is screwed in position. After this is done the chamber is filled with a melted insulating substance through a hole in the top which is afterwards sealed up with an iron screw plug.

At the front end vulcanised rubber leads are connected to the terminals and then pass backwards through the perforated sides of the box as shown, to the open wires or direct to an instrument. The lid covers all the front and protects from the weather.

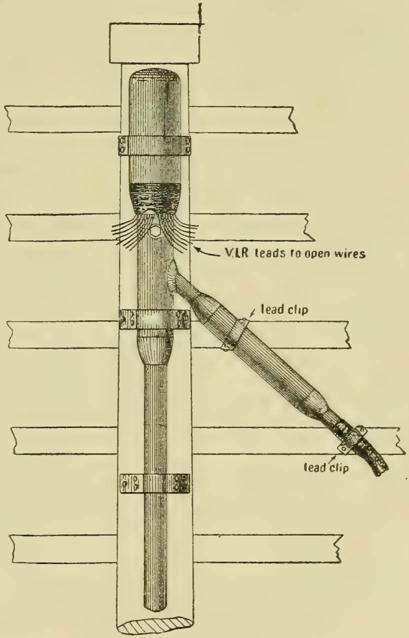


Fig. 399.—Cable Pothead Joint on Pole (Scale $\frac{1}{20}$)

Silk and Cotton Cable.—In large exchanges, where distributing frames are used, it is now the practice to make ordinary splice joints to the dry-core cables with lead-covered silk and cotton cable, so that the leading-in wires may occupy but little space. The splice joint is filled up with pothead composition * after the wiped joints are made at the ends of the lead sleeve, holes being made in the sleeve to allow the hot compound to run in properly. These holes are afterwards soldered up. Both ends of the silk and cotton cable are sealed with paraffin wax or beeswax to prevent the entrance of moisture.

Distribution.—From a manhole or split pipe near the substation to be served, subsidiary iron ducts are laid to some central point. Through these, dry-core cables are run to the most convenient point for distribution. If there are seven

* Thinned by an addition of beeswax.

or more sub-stations in any one building, the cable is carried directly into the building, and terminated in a pothead or cable-head; otherwise the cable up to 52 pairs is terminated by a pothead on or near a central distributing pole, from which the connecting or "drop" wires are radiated off to the various offices by overhead bronze wires, or by aerial cable.

The position of such distributing poles needs very careful selection in order that the "drop" lines may be as short as possible, and to avoid the necessity of carrying such lines over main thoroughfares, especially such as are fitted for electric traction with overhead feeders.

"Taper" and "Multiple" Systems of Distribution.—In running cables to serve a certain district there are two methods of distribution which may be adopted—viz. (1) the "taper" system, and (2) the "multiple" system. In the former the size of cable used gradually becomes less and less, the farther it is run from the exchange, any one pair of wires being terminated only at some one distributing point along the route; whilst in the "multiple" system of distribution the size of the cable remains the same, or nearly the same, to a point at a considerable distance from the exchange; at intermediate points branch or "T" connections are made to the different pairs in the cables, so that any one pair of wires may be connected to several distributing points. At any one of these points the particular pair of wires may be connected through to the exchange.

Where there are many changes, in the way of subscribers' removals, etc., in an area, the "multiple" system is found to be much more flexible and convenient than the "taper," although at first a greater mileage of wire may be lying idle in the cables. In many cases also the cost has been found ultimately to be less—in some cases as much as 18 per cent. less.

A combination of the two systems is often found to work best, the cables being tapered to a certain point and then multiplied afterwards, or *vice versâ*.

Location of Exchange Premises.—In deciding upon the position of a new exchange centre it is most important, especially for underground work, that the point chosen should be such as to require the minimum mileage of wire to join up the subscribers, but due consideration must be given to other circumstances, such as rental, convenient routes, etc.

To obtain the theoretical centre for the exchange a plan

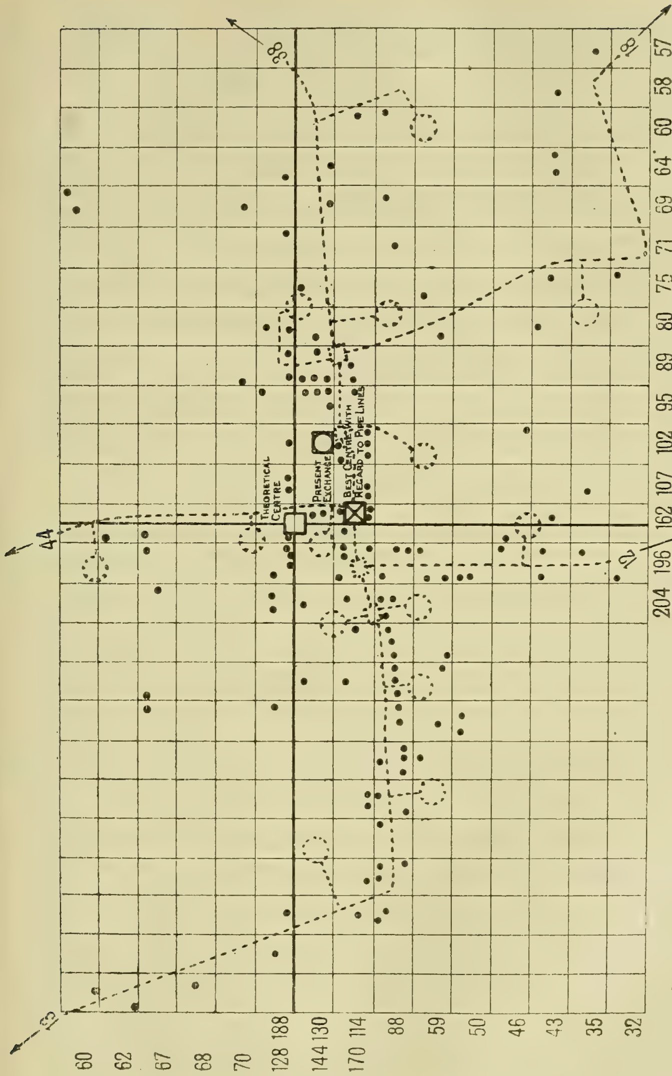


Fig. 400.—Method of finding Theoretical Centre for Exchange

of the town on a large scale is used, on which the position of each subscriber should be indicated by a dot. A tracing of these dots is made on squared paper, and the dots in vertical columns are added up and carried forward, first, say, from east to west and then independently from west to east. By this means a vertical line can be drawn dividing the dots into two equal easterly and westerly divisions. In a similar manner a horizontal line can be drawn giving equal north and south divisions, and the theoretical centre is at the point of intersection of the division lines. This method is illustrated in Fig. 400.

The actual centre should be settled as near the theoretical centre as is practicable, consideration being given to the best routes for the running of lines overhead or underground, and to the probable future development of the different portions of the district. On Fig. 400 the plan of an underground system is shown in dotted lines, the dotted squares representing manholes, and the dotted circles distributing-centres.

Electrolysis of Cables.—Much trouble has been caused to underground cables of late years in large towns in America by the lead sheathings having become corroded and perforated, and so admitting moisture. This trouble has been traced to the electrolytic action of stray currents from electric supply systems where inadequate return circuits have been provided. Corrosion only occurs at the points at which the leakage current leaves the cables, and not at the entering points, the lead being as it were carried away by the current. The most troublesome points were generally found somewhere near the generating stations, and such points should be specially watched, and the lead sheaths and iron containing pipes well "bonded" (or connected together by thick copper wire or bands) and joined to some good earth connection, or even carried through to the generating station, so that leakage currents may be conducted harmlessly away. But little trouble is experienced in this country from this cause. For further particulars see paper by Professor Haldane Gee on "Electrolytic Corrosion," read before the Institute of Electrical Engineers at Manchester on 31st March 1908.

CHAPTER XXVI

LONG-DISTANCE LINES—PUPIN SYSTEM OF LINE LOADING

When speaking has to be carried on over long lines, the conditions of the circuit must be good in all respects if good transmission is to result. All points which affect the electrical condition of the lines must be carefully considered.

The essential difference between the transmission of speech over short lines and over lines of hundreds of miles in length, is that in the latter the electrical speech impulses are transmitted in the form of elastic undulations of electro-magnetic waves, whilst the short lines do not allow these waves to form, the reflections of the impulse at the terminal instruments interfering with the advance of the wave crest.

The character of every circuit is dependent upon its four primary electrical constants—viz. (1) Resistance; (2) Capacity; (3) Inductance; and (4) Leakage, or Insulation. On the magnitude and mutual relation of these constants the efficiency depends.

As an electro-magnetic impulse progresses along the line, it is subjected to two deteriorating influences—viz. Attenuation and Distortion.

Attenuation.—This is simply a gradual falling away of the amplitude of the vibration or impulse due to the ohmic resistance or frictional loss in the conductor, the reaction from the inductive actions upon surrounding bodies, and the shunting effect of leakage from the line. Attenuation in itself is not harmful if not carried too far, so that extremely high resistances of the practically non-inductive type, such as that of resistance boxes, may be easily spoken through, as in such circuits only attenuation results, and no distortion.

Distortion.—This is due to the fact that waves of different periods or rates of vibration are unequally affected. As pointed out in Chapter III., speech waves are made up of combinations of waves of various frequencies and of various relative strengths, so that any sounded word has (when shown in graphic form) a certain definite wave shape. Fig. 401 shows the shape of the continuous wave corresponding to the vibration of air or strength of telephonic currents produced when the vowels " A " and " OO " as sounded in " pay " and " poor " are directed into a telephone transmitter. If the relative proportions or positions of the subsidiary waves are altered in telephonic transmission, " distortion " results, the special quality of the sound is lost, and the words may become

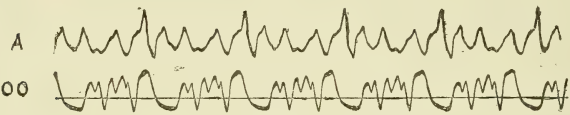


Fig. 401.—Vowel Wave Forms

indistinguishable, even though the volume of sound may be large.

Capacity.—The effect of capacity by itself on transmission is that a proportion of each wave is absorbed and redischarged, which results in the waves being levelled down, and also in " retardation " in the speed of the transmission wave. The higher the periodicity of the waves the more they are distorted by the capacity, so that, in a line having high capacity, waves of high pitch may be wiped out, and only low-pitched sounds transmitted, and the character of the sound received is altogether different to that impressed on the transmitter.

As the capacity of underground lines is very much greater than that of open lines, it will be seen how advisable it is to use the latter for long-distance working.

Inductance.—The effect of inductance is to slow down the velocity of propagation as does capacity, but at the same time

to increase the storage of electro-magnetic energy in the medium surrounding the wires by imparting what is analogous to mechanical inertia. See also page 408.

Although the effects of capacity and inductance on transmission waves are somewhat similar, they have a certain difference, inasmuch as capacity produces a "lead" in the resultant wave (that is to say, any "phase" in the resultant wave is earlier than a similar phase of the impressed E.M.F.), whilst inductance produces a "lag" in the wave, any "phase" of the wave occurring later than the same phase of the E.M.F. wave.

Mr O. Heaviside has shown in his mathematical investigations of wave transmission that if the measures of attenuation and distortion are expressed by A and D, $A = \frac{R}{2L} + \frac{S}{2K}$ (1), and $D = \frac{R}{2L} - \frac{S}{2K}$ (2), R, K, L, and S representing the resistance, capacity, inductance, and leakance conductance respectively per unit of length of the circuit. It will be easily seen that both A and D are increased by increasing R, but are diminished by increasing L; also, that an increase of leakance (S) augments A and reduces D, whilst an increase of capacity (K) increases D and may lessen A. These results, however, do not hold good under all values of the four constants; for example, if S has a fixed value there is a maximum for L, beyond which any further increase does more harm than good, as will be shown presently.

In actual telephone lines there is far more capacity than inductance, but any of the latter which exists tends to reduce the retarding and distortive effects of the capacity if it is uniformly distributed on the circuit. Neither capacity nor inductance of themselves reduce the energy of the current waves, but are regulative, whilst resistance and leakance do reduce the energy in transmission, or are "dissipative."

The wires of a loop circuit are much wider apart in overhead lines than those in cables (about 150 times greater). The capacity of cable loops is, therefore, much greater, whilst

the inductance of the cable lines is less, the proximity of the wires diminishing their inductance, as, the currents or waves moving in opposite directions in the two wires, each wire opposes the self-inductive action of the other.

Speaking from analogy, the effect of capacity in an electric circuit is similar to that of elasticity in the sides of a tube containing a fluid. The effect of inductance is similar to that of density or weight in the fluid, which, by adding momentum, enables an impulse given at one end of the tube to travel farther through the tube against the friction against the sides of the tube, which is analogous to electrical resistance.

Leakance.—The effect of leakage through the supports of open lines, or through the dielectric coverings of cable wires, is to attenuate the waves by loss of current. If in excess, the waves are considerably reduced, and little is left to act on the receiver; but, as in the case of resistance, it does not alter the articulation of the received sounds, as it affects waves of all periods equally, and no distortion is produced. A moderate amount of leakage in a line is actually beneficial, as it neutralises the capacity effect by reducing the charges. It has often been noticed that speaking on a long line having good insulation has been improved on a rainy day. Patents have also been granted for the addition of permanent leaks in cable lines, with the same object in view.

Loaded Lines.—About 1885 Mr O. Heaviside showed mathematically that, by adding inductance to a line having excess of capacity, the distortion of telephonic waves might be prevented, and the speaking improved. As the capacity of a line was uniformly distributed, he pointed out that it was also necessary to distribute the inductance in a proper manner over the line. To obtain this, he suggested the covering of the copper wires with a coating of iron filings embedded in an insulating medium, or with wrappings of iron wires, or providing the copper conductors with an iron core. The iron, wire wrapping has since been tried, and has proved to some extent a success, in spite of the fact that, by increasing the size of the wire, the capacity was also increased. Mr Heavi-

side also suggested the addition of separate inductance coils to the line, at regular intervals, for the same purpose.

In 1891 Prof. S. P. Thompson took out a patent for the improvement of cables for telephoning, in which he showed various methods of constructing the conductors and of adding the inductance coils (such as in series, in shunt, as repeating coils, etc.) in order to counteract the capacity. He pointed out that it was necessary to connect the coils at sufficiently short intervals, and also that it was preferable not to use iron cores in the coils.

Although Prof. Thompson's patents appeared to contain all the practical essentials for improving cable telephony, the matter appears to have hung fire until the year 1900, when Prof. Pupin of America took out a patent for improving the speaking on long telephone lines. His chief discovery was in the nature of a mathematical formula, by means of which he was enabled to determine the maximum distances apart which the added balancing inductance coils (joined up in series in the line) should be placed in order to approximate in efficiency to an equal uniformly distributed inductance. An outline of Prof. Pupin's theory will be given later as it has become of much importance.

Wave Length.—As pointed out by Mr Heaviside, the velocity with which electrical waves are propagated over a line may vary from an inch, or less, to 186,000 miles per second, according to the value of the resistance, capacity, and inductance of the line. The less the velocity the shorter will be the wave length for any one frequency of alternation. For any definite frequency, the formula for the wave length (w) on a line takes the form of : $\mathrm{W} = \frac{2\pi}{a}$, in which a is called the *wave-length constant* or *factor*, and has the following value :—

$$a = \sqrt{\tfrac{1}{2}\sqrt{(\mathrm{R}^2 + p^2\mathrm{L}^2)(\mathrm{S}^2 + p^2\mathrm{K}^2)} - \tfrac{1}{2}(\mathrm{RS} - \mathrm{LK}p^2)} \quad (3)$$

R being the resistance, K the capacity, L the inductance, and S the leakance, are the values per mile of the loop line, and p has the value $2\pi n$, n being the frequency per second, and

$\pi = 3{\cdot}1416$ the ratio of the circumference to the diameter of a circle.

Attenuation Coefficient.—Suppose a wave or impulse to start with an amplitude of, say, 100, then at a distance of m miles from the starting point the amplitude will be reduced to $100\epsilon^{-\beta m}$ which is equal to $\frac{100}{\epsilon^{\beta m}}$. This ϵ represents the number 2·718, which is the base of Naperian or natural logarithms, and β represents the *attenuation coefficient* or *constant* obtained by working out this formula :

$$\beta = \sqrt{\tfrac{1}{2}\sqrt{(\mathrm{R}^2+p^2\mathrm{L}^2)(\mathrm{S}^2+p^2\mathrm{K}^2)}+\tfrac{1}{2}(\mathrm{RS}-\mathrm{LK}p^2)} \quad (4)$$

This, it will be seen, is similar to the wave-length constant, except in the sign of the last term.

There are several interesting special cases of No. 4 formula in which it becomes much simplified. First suppose S and L to be very small, as is the case in most cables, where they may be neglected, No. 4 formula then becomes $\beta = \sqrt{\frac{p\mathrm{KR}}{2}}$ (5), showing that attenuation increases with the frequency. Again let $\frac{\mathrm{L}}{\mathrm{R}} = \frac{\mathrm{K}}{\mathrm{S}}$ and then β reduces to $= \sqrt{\mathrm{RS}}$ (6), which is a quantity quite independent of the frequency. This state represents a distortionless circuit, as shown by Heaviside. Again, let L and p L be large in comparison with R, and we shall then find that β will approximately $= \frac{\mathrm{R}}{2}\sqrt{\frac{\mathrm{K}}{\mathrm{L}}}$ (7), which is again independent of the frequency factor, and is, therefore, the equation of a distortionless line, as all frequencies are equally attenuated.

Of the two distortionless conditions (6) and (7) the latter or "inductance" line is the most practical. Heaviside's "leakance" distortionless circuit is theoretically the more perfect of the two as regards distortion only, but unfortunately it entails a larger attenuation in general and in the case of the small conductors used in telephone cables a much larger attenuation than in the normal circuit. On the other hand the "in-

ductance" line has a smaller attenuation besides approximating to the distortionless conditions. As a good volume is as essential as clearness it is clear that the "inductance" loading is the better solution of the problem.

Sine Wave.—In order to understand Pupin's theory it is necessary to understand what is meant by a "sine wave." In Fig. 402 the wave form A A A represents such a sine wave, such as may be generated by the steady revolution of the armature of a magneto-generator such as shown at Fig. 402. The circles on the left represent the angular motion of the armature to produce the wave, and the dotted lines show how

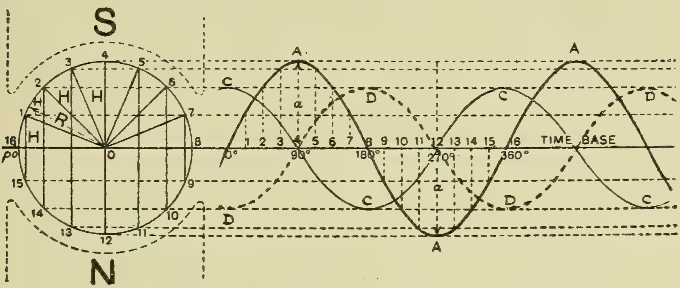


Fig. 402.—Sine Wave Diagram

the wave curve is plotted from the angles. Distances measured to the right represent the time taken in making the revolution. Although telephonic speaking waves are of a very complicated nature, it has been found that they are all compounded of a number of such simple sine waves of various frequencies.

The smaller waves C C C and D D D show the nature of additional waves which are added, and modify the shape of the original wave when capacity and inductance are present in a circuit.

It will be noticed that the capacity wave C C C is at its greatest positive value at the same time that the inductance wave is at its greatest negative value, and it is easy to see that if both effects acted equally in the same circuit the two would

neutralise each other, and the original wave would travel on unaffected. It will also be seen that any point of the capacity wave C C C is 90° earlier, and any point of the inductance wave D D D is 90° later, than the corresponding points or "phases" of the A A A wave.

The actual current wave will be modified according to the proportions of the two effects present, so that it will have a certain amount of "lead" or "lag," according to the relative value of the capacity or inductance, or both, present in the circuit.

Pupin's Theory.—Prof. Pupin pointed out that in loading a circuit with inductance coils it was necessary for efficiency that there should be a number of coils to each wave length to be transmitted through the line. If W, the wave length, be taken as a complete revolution, or 360° (see Fig. 402), or in angular measurement (where the unit is $\frac{360}{2\pi}$ or $57{\cdot}3°) = 2\pi$, and the length l of the fraction of a wave length between any two of the loading coils be also given in angular measure $= 2\pi\frac{l}{W}$, then the nearness with which the value of one half of the sine of the angle $2\pi\frac{l}{W}$ approximates to the value of one half of the angle itself will represent the approximation of the efficiency of the loaded line to that of a line on which the inductance of equal value is spread uniformly over the line.

To illustrate his theory, Prof. Pupin made use of the following mechanical analogy:—A cord is fastened to one prong of a tuning fork and to a fixed support, as in (1) of Fig. 403. If the fork be set in vibration, the cord vibrates, and waves are transmitted along it, as in (2), if there is but little friction between the particles of the cord; if there is much of such friction, the amplitude of the waves fall off at the fixed end, as in (3), representing attenuation, which becomes greater the longer the cord. This loss will be less the heavier the cord, the weight giving it greater momentum,

but it will require more force to set it in motion. If a single weight be attached to the centre of the light cord, the wave will not travel along it properly, but if this weight be subdivided, and the parts distributed at equal distances along the cord, as in (4), the cord will vibrate like a heavier cord, and waves will be transmitted with but little attenuation.

The weights are the equivalent of inductance; the friction of electrical resistance, and the elasticity of the cord represents the electrical capacity.

Practical Application.—A frequency of 750 cycles per second is usually taken as a standard, as being about midway

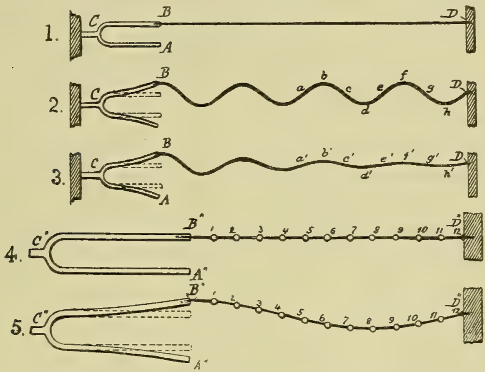


Fig. 403.—Effect of Loading on Vibrating Cord

between the lowest and the highest important frequency of about 1500 per second, as shown by Cohen and Shepherd in their paper read before the I.E.E. on 9th May 1907. It has also been found in practice that the attenuation determined by actual speech tests is almost identical with calculated values based upon a frequency of between 750 and 850 cycles per second. If a line is corrected for this value it will be still more nearly correct for less rapid waves.

Having fixed upon the amount of attenuation to be allowed for the above frequency, so as to leave a sufficient strength to ensure good speech, and the amount of inductance

to be added to the line per mile, the wave length of the line is calculated as if the inductance were uniformly distributed, and with the resistance of the coils added to that of the line. For example, take a cable 250 miles long, of 9 ohms per mile resistance, and ·074 microfarad capacity per mile, but having no appreciable inductance. Let the proposed attenuation constant B = ·015, or $\frac{1}{66}$th. Suppose inductance of ·056 henry added per mile by coils having a resistance of 9 ohms per mile. The wave length for 750 alternations would then be 14·6 miles if the inductance were uniformly distributed. If

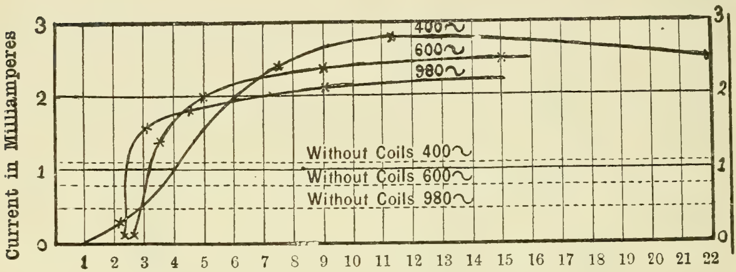


Fig. 404.—Effect of Loading on Received Currents

in loading, a coil were joined in the line at every mile, the proportion of W to l will be as 14·5 to 1, and the angular measure $2\pi\frac{l}{W}$ will be $\frac{2 \times 3{\cdot}1416}{14{\cdot}5} = {\cdot}433$ radians. The sine of one half of this angle ($=12{\cdot}4°$) is $={\cdot}214$, so that the efficiency of the loaded line will be to a uniform one, as ·214 is to ·217 $\left(=\frac{{\cdot}433}{2}\right)$ or over 98 per cent., the attenuation becoming ·0148 instead of ·015.

Fig. 404 shows some curves obtained practically on a loaded line in Germany through a dry-core cable 17·4 miles in length, with current having frequencies of 980, 600, and 400 alternations per second, the wave lengths being respectively 8, 13, and 20 miles. The curves show the relation between the strength of the current sent out and that received with the

several periodicities, as the number of coils per wave length was varied, the initial current being 3 milliamperes in each case. The curves show that in loading a line there should not be less than 4 coils per wave length, and there need not be more than about 10.

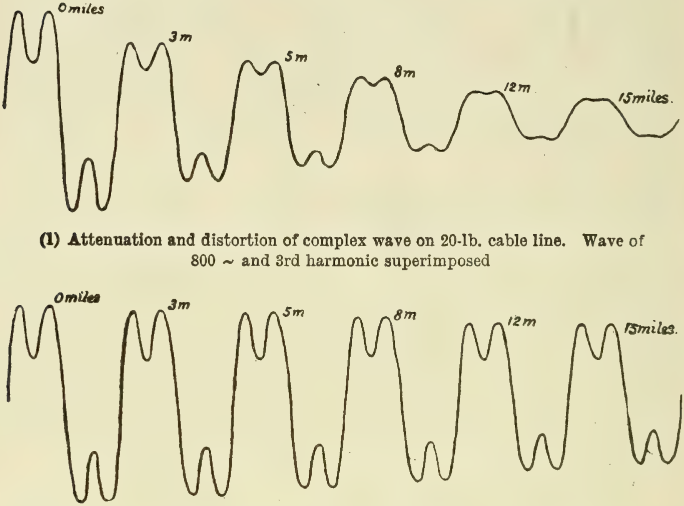
The experimenters (Messrs Dolezalck & Ebeling) responsible for the above curves also made experiments on the loading of both cable and open wires in Germany, and proved that the beneficial effect was unmistakable. They stated that the same efficiency could be obtained by loading on lines of the same length and one fourth the weight of copper; or with the same weight of copper at least four times the distance could be surmounted.

The No. 1 curve of Fig. 405 illustrates the effect of transmission through 15 miles of an ordinary unloaded cable of a compound wave made up of two waves of different periodicities. It will be seen how great is the attenuation, especially of the high-frequency wavelet, which has almost disappeared, so that the shape of the wave is different at the end to what it was at the commencement. The distortion due to displacement owing to the different speeds of propagation is not, however, shown.

In the No. 2 diagram the effect of loading on the transmission is shown, the attenuation of both constituent waves being much reduced, but, being proportionally equal, no distortion results.

Wave Reflection and Tapering.—As with other wave motions, such as those of sound and light, partial reflections of the wave, giving rise to loss of energy, take place when an electrical wave passes from one class or quality of conducting media to another, as from a conducting path, such as an open line wire, having low inductance to one having high inductance, such as the loading coils on a line or the telephone instruments at the ends of the line, or *vice versâ*. The greater the difference in homogeneity the larger the reflections. Such reflections considerably attenuate the wave by reducing the portion going forward. If the loading coils are sufficiently

numerous but little reflection takes place on the line, but the reflection may be severe when a loaded line is connected to an unloaded line. To prevent such losses, "tapering" is resorted to, which consists in gradually reducing the inductance of the loading coils towards the ends of a long loaded



(1) Attenuation and distortion of complex wave on 20-lb. cable line. Wave of 800 ~ and 3rd harmonic superimposed

(2) Attenuation and distortion of same wave over same line, but inductance of ·2 henry per mile added

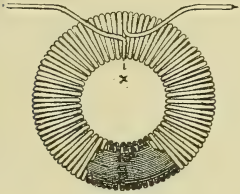
Fig. 405

line. This is found to very much improve the results obtained both in volume and quality.

Another and a simpler method of improving the terminal conditions is to fit "step-up" repeating coils or transformers at the ends of the line. The theory of this arrangement has been dealt with by G. A. Campbell ("Loaded Lines," *Philosophical Magazine*, 1903). Expressed briefly it means that the impedance of the transformer on the secondary or live side should be equal to that of the loaded line itself. Virtually the effect is similar to that of rewinding the instrument with more turns

of wire, so as to accommodate it to the higher potential working conditions of the loaded circuit.

Construction of Coils.—The construction of the loading coils to be used on circuits is a matter requiring much consideration, as it is necessary that as little as possible of the energy of the waves shall be dissipated by the formation of Foucault or eddy currents, and if iron cores be used, by hysteresis losses. To keep the coils within reasonable size, it is necessary to use iron cores. Prof. Pupin pointed out that to prevent loss of energy by hysteresis it was necessary to use a comparatively large body of iron, so that the intensity of magnetism per unit of sectional area may be kept low;



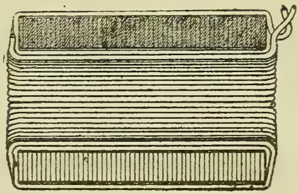


Fig 406. Scale ½ Fig. 407

and to prevent loss by Foucault currents, such iron should be in the form of very fine iron wire, wound at right angles to the conductor coils, such as shown in Figs. 406 and 407, which show the form of coil suggested by Prof. Pupin, the iron wire being varnished, to prevent side contact. The core of such coils may also be built up of very thin ring plates slotted from centre outward. Fig. 407 shows such plates in section.

The coils to be used on aerial lines are usually large, and wound with thicker wire, than those intended for cable lines.

Results of Loading in America.—Many interesting details of the practical results of "loading" were given in a paper by Dr H. V. Hayes, read before the International

Electrical Congress at St Louis in 1905. A spacing of the coils at such uniform distances apart on the lines that an electrical wave front passed through 7000 coils per second was found to give good results. This corresponds to $\frac{7000}{750} = 9{\cdot}3$ coils per wave length for a 750 periodicity.

If a line has a considerable amount of inductance the wave velocity is approximately $\frac{1}{\sqrt{LK}}$ miles per second, and if the loads are spaced at a distance "d" miles apart the number passed per second by the wave front is $\frac{1}{d\sqrt{LK}}$. 7000 per second gives good results, but it is not possible to reduce this number much without seriously interfering with articulation; on the other hand it is quite unnecessary to go beyond, say, 12,000 coils per second.

The coils used are "toroidal" in shape—that is, they are wound on a ring core of fine iron wires. They are 4·5 inches diameter and 2 inches high. Their resistance is 2·4 ohms, and inductance 0·25 henry; the *apparent* resistance at a periodicity of 2000 being about 15·5 ohms.

Cable Lines.—The curves given in Figs. 408, 409, and 410 represent only the attenuation experienced on loaded and unloaded lines, and do not show the relative quality or distortion of the received speech.

Fig. 408 gives the results obtained on a cable line having a resistance of 96 ohms and mutual capacity of 0·068 microfarad per mile of circuit. The loading coils added 0·6 henry per mile. Curve No. 1 represents the attenuation on unloaded lines, and No. 2 the attenuation when loaded, but no terminal tapering is used; whilst No. 3 gives the same when tapering is added at the ends. The dotted curve gives the attenuation of the same line *without tapering* when loaded to only about 0·17 henry per mile.

It will be noticed what a great difference the tapering makes on a heavily-loaded line by reducing the reflection

losses, and also that for short lines the unloaded line gives better results than the loaded one.

Open Lines.—Figs. 409 and 410 represent the same results obtained on open lines—the first of copper 435 lbs. to the mile and the other of 176 lbs. per mile, both loaded to about

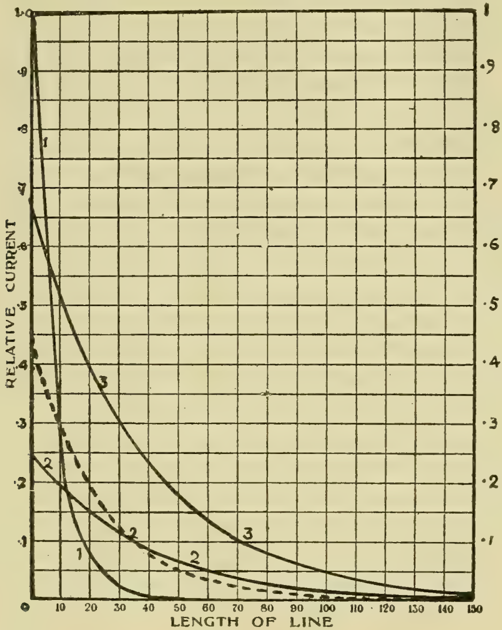


Fig. 408.—Effect of Loading on Cable Lines

0·1 henry per mile. It will be noticed that the relative advantage of loading even with tapers is not so great as in the case of cable lines, as seen by the relative slope of the curves.

According to theory a line may be loaded to any extent provided its insulation be very high, but if insulation be low the inductance it is possible to add with beneficial results is limited, as will be seen from Heaviside's relation $\frac{L}{R} = \frac{K}{S}$ or $L = \frac{RK}{S}$.

If higher inductance than this is added attenuation will rapidly increase instead of diminishing. This is the principal factor in limiting the loading of open wires.

Quality.—The distortion of the waves on loaded cable lines is markedly lessened, whilst with loaded open lines this is not the

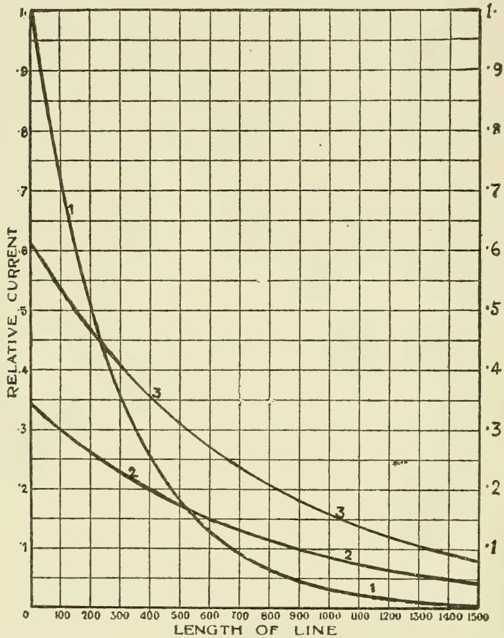


Fig. 409.—Effect of Loading on Heavy Aerial Lines

case. The latter result is mostly due to the effect of leakage, which on open lines is variable, and much greater than with cable lines, and is increased by the loading coils. The distortion on ordinary open lines is very small, and it has been found in many cases that loading coils actually increase it, so that although the volume of the received sound may be increased by loading, the quality is actually poorer than on unloaded lines.

For these reasons the loading system cannot, so far, be considered a success for open lines, but for cable lines it has proved an undoubted success.

Theory of Line Transmission.—The telephone transmitter can only furnish a certain definite amount of energy for trans-

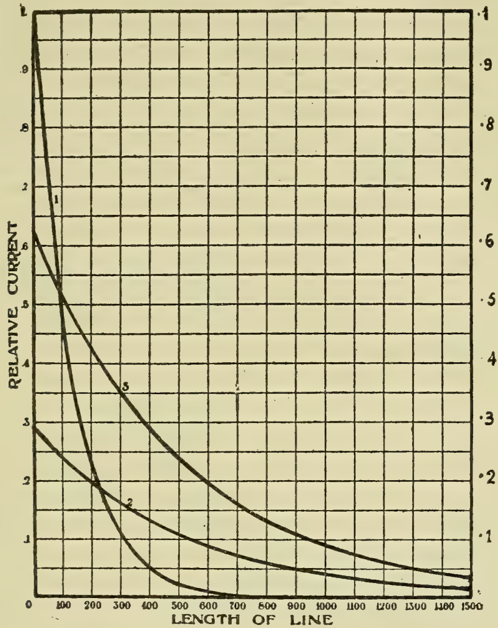


Fig. 410.—Effect of Loading on Light Aerial Lines

mission along the circuit, and this energy may be conveyed by a current which diminishes as the self-induction increases so that there are smaller C^2R or heat losses in the conductor and consequently less attenuation. The addition of inductance also brings about a modification in the transmission which becomes obvious when the mathematical expression for the attenuation constant β is examined, as the terms involving frequency become of minor or no importance as is seen in

formulæ 6 and 7 on page 406, so that distortion is removed or greatly reduced.

Terminal Effects.—In most elementary discussions on the theory of wave propagation over telephone lines, the effect of the terminal apparatus is ignored, or the line is assumed to be extremely long and to be by far the most important part of the circuit electrically. This, however, is only the case in practice where long trunk lines are concerned. The theory of terminal reaction is of too intricate a nature to be dealt with fully here; it has been treated very fully by O. Heaviside in his Electrical Papers, but his formulæ are involved and cumbrous for practical use. Dr A. E. Kennelly has introduced several very convenient formulæ and a very useful form of notation which may be briefly given here:

Keeping the same notation as before for the line constants per loop mile, two further constants are defined as follows:—

a = a constant which may be called the transmission constant $= \sqrt{(R + j\,pL)(S + jpK)}$

z_0 = the line impedance $= \sqrt{\dfrac{R + jpL}{S + jpK}}$

j being $= \sqrt{-1}$ and $p = 2\pi$ times the frequency as before $= 2\pi n$.

In order to translate these and similar mathematical forms into arithmetic, it is necessary to know a little vector algebra. j is a symbol for perpendicularity, and any expression like $a + jb$ is called a complex quantity, which means the resultant of a horizontal step $\underline{a}$ + a vertical step $\underline{jb}$. $a + jb$ is numerically $= \sqrt{a^2 + b^2}$, and is a vector inclined to the horizontal at an angle whose tangent is $\frac{b}{a}$ (for short $\tan^{-1}\frac{b}{a}$). A very convenient method of expressing such a vector is $A/\underline{\theta}$ where A is the square root of the sum of the squares of the real and imaginary (j) components, or the *size* of the vector, and θ its angle. Vectors are multiplied and divided according to the following rules:—

$$A/\underline{\theta} \times B/\underline{\phi} = AB/\underline{\theta + \phi}$$

$$\frac{A/\underline{\theta}}{B/\underline{\phi}} = \frac{A}{B}/\underline{\theta - \phi}$$

Also $\sqrt{A/\underline{\theta}} = \sqrt{A}/\underline{\theta/2}$

To add or subtract vectors, they must be expressed as complex quantities, and the real and j terms added or subtracted separately. Thus :

$$(a+jb) \pm (c+jd) = (a+c) \pm j(b+d)$$
$$= \sqrt{(a+c)^2+(b+d)^2}\,\Big/\tan^{-1} \pm \frac{b+d}{a+c}$$

As an example.

If $R = 88\omega$

$C = .054 \times 10^{-6}$ farads $\qquad pC = 270 \times 10^{-6}$

$L = 001$ henry $\qquad pL = 5$

$S = 5 \times 10^{-6}$

$p = 5000$

$$a = \sqrt{(88+j5)(5+j270)\ 10^{-5}}$$

$$= \sqrt{88 \cdot 142/\underline{3^0.15^1} \times 270 \cdot 046\ /\underline{88^0 56^1} \times 10^{-6}} = \cdot 15428/\underline{46^0 6^1}$$

and $$Z_O = \sqrt{\frac{88 \cdot 142/\underline{3^0 15^1} \times 10^6}{270 \cdot 046/\underline{88^0 56^1}}} = 571 \cdot 31^{\omega}\ \overline{\diagdown 42^0 51^1}\ \text{ohms}$$

Note that a larger angle subtracted from a smaller produces a negative angle, $\triangledown$ measured downwards.

Now the current that enters the line at the sending end and that which enters the instrument at the receiving end may be found by dividing the initial P.D. by a quantity equivalent to a resistance and termed the "sending end" impedance and the "distant end" impedance respectively and designated by Z_S and Z_R.

These quantities are defined thus $$Z_S = Z_O\left\{\frac{\frac{Z_A}{Z_O} + \tanh(la)}{1 + \frac{Z_A}{Z_O}\tanh(la)}\right\}$$

and $Z_R = Z_O \sinh(la) + Z_A \cosh(la)$

l being the length of line and Z_A the impedance of the receiver $= \sqrt{R^2+p^2L^2}$. R and L being effective resistance and inductance.

The Hyperbolic Sine and Cosine of (la) are functions of a

complex quantity *not* a mere number, and must be computed by the following vector formulæ :—

Sinh (x + jy) = sinh, x cosy + cosy + j cosh x sin y (1)

Cosh (x + jy) = cosh x cosy + j sinh x sin y (2)

Where x and y are the horizontal and vertical components of (1a). Sinh x and cosh x are read from ordinary Hyperbolic tables and sin y and cos y are radian measure.

These expressions (1) and (2) when put into the working form $A \underline{/\theta}$ become:

$$\sqrt{\sinh^2 x \cos^2 y + \cosh^2 x \sin^2 y} \; \underline{/\tan^{-1} \frac{\tan y}{\tanh x}}$$

and $\sqrt{\cosh^2 x \cos^2 y + \sinh^2 x \cos^2 y} \; \underline{/\tan^{-1} \tanh x \tan y}$

respectively. With this data it is comparatively easy to calculate Z_S and Z_R. The latter is a most important quantity, as it determines the current delivered to the receiving apparatus. The formulæ are really more difficult to describe than to use. For more detailed information on this subject a reference to Dr Kennelly's invaluable papers (*Harvard Engineering Journal*, November *et seq.*, 1905) or an excellent series of articles by Dr C. V. Drysdale (*Electrician*, December 6, 13, 30, 27 of 1907 and 10th January of 1908) should certainly be made.

Having obtained z_R and z_S, the received current and the transmitted current are given at once by $C_R = \frac{v}{Z_R}$ and $C_S = \frac{v}{Z_S}$ amps. if v the sending end P.D. is in volts.

The K.R. Rule.—On lines in which the inductance and leakance is very small and may be neglected, such as the twin wires of an underground or submarine line, the old K R rule (that the efficiency of speech is inversely proportional to the product of the total resistance of the line into the total mutual capacity of the line, or to K × R) will roughly apply. The same product is obtained by multiplying the resistance per mile (r) into the mutual capacity per mile (k), and this again by the square of the length in miles (L) or $L^2\, r\, k$.

The K R for a single line and earth circuit line has been

generally considered to be about the same as for a metallic circuit line of the same length and size of conductor, as it was thought that, although the resistance of the latter is double that of the single line, the mutual capacity of the metallic circuit was about one-half the capacity of the single line. Late measurements have, however, shown that the mutual capacity for cable wires is about 0·66 of that of a single wire and earth, so that the above rule does not hold good.

Standard Cable and Equivalents.—In the agreement entered into in February 1905 between the British Post Office and the National Telephone Co. certain standards of telephonic transmission were stipulated, and these were to be measured by comparison with the transmission results obtained with standard telephone instruments through certain lengths of standard test cable. This cable is of dry-core type, with the following measurements per mile :—conductors 20 lbs. and ·036 inch diameter, an average mutual capacity of 0·054 microfarad loop resistance of 88 ohms, and an insulation resistance between the wires of a pair of not less than 200 megohms per mile. (For text of agreement as regards electrical conditions of plant see Appendix.)

Post Office Trunk Lines.—As previously mentioned, in Chapter XIX., the British Post Office authorities have constructed an extensive system of trunk lines for joining up all the town in the kingdom. The principal feature of this system is a backbone of 800-lb. copper wire, which runs from London through Birmingham, Leeds, to Glasgow. This weight of wire is only used for the longest circuits. For shorter circuits, such as between London and Manchester or Liverpool, circuits of 600-lb. copper wire is used, and from London to Manchester and Liverpool 400-lb copper is used. The subsidiary centres are joined up to the main centres by 300 or 200 or 150 lb. wire, according to their distance apart, or to what circuits they are to be joined.

In the Appendix is a table giving various particulars of the wire used for trunk and other lines, and also formulæ for the calculation of the capacity and inductance of lines.

CHAPTER XXVII

SUBMARINE TELEPHONE CABLES

The cables for telephone working laid between Scotland and Ireland, England and France, England and Belgium, are all of the type shown in full-sized section in Fig. 411. This represents the latest and longest of such cables. It is 54 miles long, and is laid between St Margaret's Bay and La Panne in Belgium. The four conductors (for two circuits) are each made up of 7 strands of 20 lbs. per mile copper wire, the whole weighng 140 lbs. per mile, and having a resistance of 6·4 ohms per mile. Each of these conductors is coated with gutta-percha and Chatterton compound, and then formed round a core and made cylindrical with tarred hemp. Over this is a layer of ozokerited cotton tape, on which is wound brass tape, as protection against the teredo, a submarine animal. Over this is ozokerited cotton tape, then tanned Russian hemp, over which is wound an armour of 16 galvanised iron wires, each 0·28 inch diameter, coated with gas tar. The whole is covered with two windings of tarred hemp.

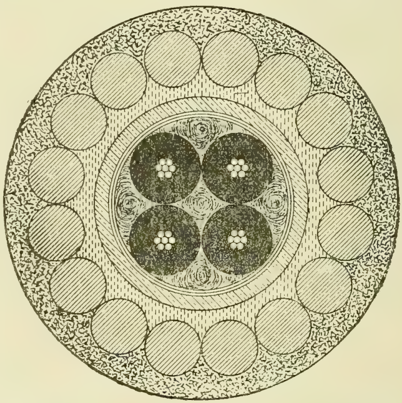


Fig. 411.—Section of Anglo-Belgian Cable (Full size)

The capacity to earth per conductor is to be not more than

0·275 microfarad per mile, and the insulation resistance not less than 500 megohms. The total resistance of each conductor at 46·5° F. was found to be 331·4 ohms, and the capacity to earth 12·617 microfarads.

For the London-Paris line there are three such cables, each 24·25 miles long, laid between St Margaret's and Sangatte in France.

The Irish Cable is 26·5 miles long, laid between Port Kail in Scotland and Donaghadee in Ireland.

Later Forms of Submarine Telephone Cables.—In order to increase the speaking efficiency of submarine cables and at the same time reduce their cost, endeavours have been made in two directions. (A) By the addition of increased distributed inductance over the conductors by the addition of wrappings of fine iron wire, and (B) by the insertion at certain intervals along the cable of Pupin coils into the circuits. Both these methods have the effect of neutralising to some extent the detrimental effect of the capacity on the speaking transmission.*

(A) *Distributed Inductance.*—This system has been used with several submarine cables joining Continental towns but not with any pronounced measure of success. One of the longest of these cables is of 19·38 kilometres length laid in 1907 between Fehmarn and Lolland. This has a 4-wire air and paper insulated core, each copper conductor being 2·15 m.m. diameter, over which is laid 3 segment copper strips, the whole being tightly bound with 3 layers of soft annealed iron wire 0·2 m.m. diameter. Over the iron wire are two coverings of paper to a diameter of 7·7 m.m. The four conductors are twisted together and covered with paper to a diameter of 20 m.m. to form the core, which is protected by two lead tubes each 1·4 m.m. thick, and these are covered with asphalted paper and jute and armoured with 13 tinned iron wires of trapezoidal cross-section as shown in Fig 412, the whole being finished off with a double jute compound covering.

* See *Electrician*, 27th November 1908 and 24th May 1907.

The electrical constants of this cable are as follows :—

Resistance per loop kilometre at 15° C.					4·81 ohms.
Capacity	,,	,,	,,	,,	0·047 m.f.
Inductance	,,	,,	,,	,,	from 0·00975 henry to 0·00984 henry.

Insulation resistance per kilometre above 1500 megohms.
Attenuation constant for a periodicity of 800, 0·0063.
Which gives a speaking range of about 400 kilometres.

Another cable of this type is laid between Cuxhaven and Heligoland, some 70 kilometres.

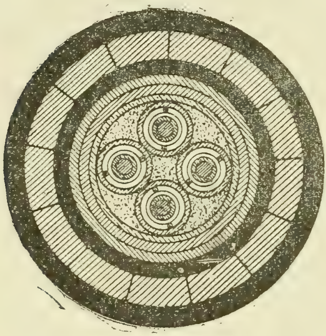


Fig. 412

(B) *Loaded Submarine Cable.*—A cable $9\frac{1}{3}$ miles long on this principle has been laid by Siemen and Halske between Friedrichshafen and Romanshorn across Lake Constance. The core consists of 7 pairs of stranded conductors with air and paper insulation, each conductor being 1·5 m.m. diameter These are covered by a lead tube over which is wound two continuous spirals of 2 m.m. diameter steel wire, which is used in order to give strength to withstand the very great water pressure to which the cable is subjected. The outer armouring is composed of 32 iron wires each 37·5 m.m. diameter. The Pupin coils are inserted into the core at distances apart of 1100 yards for each circuit but at points 550 yards apart on the cable. Special precautions had to be taken at these points to give extra strength and prevent access of water.

The stranded conductors have a cross-section of			1·77 sq. m.m.
Resistance per kilometre circuit with coils			33·5 ohms.
,,	,,	of coils	20 ohms.
Capacity	,,	,,	0·039 m.f.
Inductance	,, @ 900 frequency		0·21 henry.
Attenuation Factor	,,	,,	0·0072.
Speaking Range			347 kilometres.

MODERN SUBMARINE TELEPHONE CABLES

Date	Cable	Construction	Capacity. per K.M. Mfd.	Self-induction per K.M. Henrys	Resistance per K.M. Ohms	Damping per K.M. factor	Cross-section Sq. m.m.	Diam. m.m.	Total Range K.M.
	Refsnaes-Soelvig	G. P. and Iron wires 0·2 m.m. dia.	·12	·0087	4·55	·0084	8·6	3·3	300
1902	Fehmarn-Lolland	Lead-covered and Iron wire 0·3 m.m. dia.	·082	·0050	5·34	·0105	10·0	3·6	238
1902	Elsinore-Helsingborg	G. P. and Iron wire 0·2 m.m. dia.	·1745	·00265	4·76	·0194	1·54		130
1903	Cuxhaven - Heligoland	Lead-covered and Iron wire 0·3 m.m. dia.	·044	·0043	3·80	·0065	12·6	4·0	385
1903	Greetsiel-Borkum	Air Space Paper Cable	·0742	·00399	4·86	·0133	1·42		189
1906	Friedrichshafen-Romanshorn	A. S. P. C. Pupin cable	·039	·21	33·5	·0072	·177	1·5	347
1907	Fehmarn-Lolland	Lead-covered A. S. P. C. with Iron wire 0·2 m.m. dia.	·047	·0098	4·81	·0063		2·15	400
1907	Korsor-Zyborg	G. P.				·0120	1·84		209

It is claimed that with such loaded cables the same transmission can be obtained at a cheaper cost than with the iron wire inductance owing to the much smaller size of copper conductor that can be used.

Table.—The table on page 425 gives some of the electrical constants, etc., of several of the latest submarine telephone cables which have been laid between various towns on the continent of Europe. For further details of these cables see *The Electrician* articles referred to on page 423.

CHAPTER XXVIII

FAULTS AND THEIR LOCALISATION

Even with the best class of instruments faults occur at times which interfere with, or altogether dislocate, the working of a station or stations. In order to reduce faults as much as possible, it pays to get instruments of the best class made by firms of high reputation, as the maintenance of such instruments is much less costly than that of a cheaper grade.

In many exchanges tests are made by the operators to each subscriber every morning, of both ringing and speaking, and a list of those numbers found defective in any way is made out for further tests and rectification by the fault inspectors. Complaints of other defects are received during the day from the subscribers, or from renters of private instruments.

The most common descriptions of faults are such as—(1) *wires in contact*, (2) *can ring but cannot speak*, (3) *cannot ring*, (4) *cutting off whilst speaking*, (5) *cannot get attention*.

Such faults, with the exception of those in connection with private lines, are first reported to the test clerk in the test room, who, with his instruments, endeavours to find out something more definite in regard to them, so as to guide the fault inspectors in tracing the cause, and to determine whether any faults exist at the switch-room end of the line. The faults which are not in the switch-room are reported to the instrument fault inspectors, with the exception of those which are obviously line faults, such as contacts between wires, when ringing or speaking on one of the wires is received on the others. The cause of the latter fault can only be in the switch-room or on the lines.

When the fault inspector arrives at the subscriber's office, unless he is quite sure of the nature of the fault, before he touches the instrument he should make a few inquiries from

the person who uses it. A few judicious questions will often result in much information being elicited as to the nature of the fault, and as to that part of the instrument in which the defect will most likely be found, whether in the bell part of the circuit, the receiving part, or in the microphone circuit. For example, if the subscriber says *he can hear* from the other end perfectly, but that other people *cannot hear him* at all, it will be evident that the local microphone circuit must be faulty, or that the secondary wire of the induction coil is short-circuited. If he says *his bell rings*, but he *can neither hear nor be heard*, the speaking circuit must be looked to.

After a full inquiry, and before altering anything, the inspector should make a careful examination of the instrument, including the window terminals if the line appears to be affected. This inspection will often disclose the cause of the trouble in a broken wire, a wire out of a terminal, or, perhaps, some bare part of a wire touching another wire or terminal. A connection under a terminal may be cut through, or the terminal may be loose.

If nothing is disclosed by this survey, a good method of procedure is to quietly take up the receiver, and put it to the ear. If inductive noises are heard, such as frizzling or clicking noises, it may be assumed that there is a fault on one or both of the line wires, which has upset the balance of the line. These noises also indicate that the receiver is all right, and if the noises are not present it is a good plan to produce them by connecting one of the line wires to earth for a few moments at the lightning arrester on the instrument. The inspector should next try to call the exchange by turning the generator, and listening on the line with the receiver. If successful, it will be easy to localise the fault by calling up the test-room inspector, and testing with him the different parts of the instrument or the line wires.

If the *exchange cannot be called*, it shows that either the generator is faulty or some part of the line circuit is either disconnected or short-circuited. The line terminals on the bell should next be short-circuited with a piece of wire, and the

bell cut-out on the generator be prevented from acting by inserting a piece of paper between the contacts. If now the bell does not ring when the generator is turned, there is either a disconnection or short-circuit in bell or generator coils, or in the circuit. A short-circuit can easily be distinguished from a disconnection by the fact that the generator runs heavily and jerkily in the former case, but easily and smoothly in the latter.

If the bell does not ring, but the generator works heavily, and then works easily after the short circuit is removed from the line terminals, it may be assumed that the bell coils are short-circuited, but if no change occurs it is probable that the generator itself is short-circuited. It should be tested by connecting the galvanometer to the pole-piece, and to the spring which bears on the insulated pin at the end of the armature pivot, at the same time making a break in the bell circuit. By now turning the handle slowly it will be evident by the deflections obtained if the generator is perfect.

The above tests apply more especially to a *series-connection* bell, but they will apply to a *shunt-connection* bell by breaking the shunt contacts on the switch-hook with a piece of paper.

If in a *shunt* bell ringing is heard in the receiver when the hook is up or down, the shunt connections to the switch-hook or the connection on the hook will be faulty.

A good test of the speaking circuit is to quietly take up the receiver, put it to the ear, and blow on the transmitter. A characteristic rustling sound will be heard when the speaking circuit is right, but if this is heard when one or both of the line terminals are disconnected it will show that there is a short circuit in some of the instrument connecting wires, and breaks must be made in the circuit, and a battery cell and galvo used to find out which parts that ought to be separate are connected together, looking especially after points where wires cross each other. Screws or tacks used to fasten portions of the instrument often cause trouble by coming into contact with the connecting wires behind.

If the noise on blowing is faint, a fault may reside in the

transmitter or cell, or in the receiver, which should be examined by taking off the cap, to see if there is any loose dirt in the bobbin recess, between the pole-pieces of the magnet and the diaphragm, to account for weak vibration. Such dirt is a very frequent source of trouble, and is one of the first things to look for in inspecting an instrument.

If *ringing is all right* between the stations, but *speaking is not heard either way*, it will be evident that the secondary or main-line speaking circuit is defective. The receiver may be short-circuited or disconnected. A frequent cause of these faults is found in the connection of the flexible cord. Too much conductor is bared, and these bared parts get together, or the terminal screws work loose, and one of the conductors is pulled out. If the cord is not the faulty part, the switch-hook contact should be cleaned, and if this does not remedy the trouble the different parts of the circuit should be short-circuited one after the other until the working of the instrument is restored.

If the subscriber *can hear but cannot be heard*, the local microphone circuit is affected. The defect may be caused by a bad cell; a dirty switch-hook spring contact, the latter being bent, and failing to make a contact; a break or short circuit in some other part of the primary circuit, or in the secondary wire of the induction coil. If a close inspection does not disclose the cause, and the battery cell is proved to be in good order by testing with a galvo, the different parts of the circuit should be tested by means of a length of wire, gradually by its means bridging over successive parts of the circuit until a sound is heard in the receiver when the transmitter is blown upon. The break will then, as before, reside in the part last bridged over.

By the method of bridging over the connections when a break occurs, and of disconnecting and testing with a cell and galvo for a short circuit or earth, faults can, as a rule, be very soon located, and the necessary repairs are then a comparatively easy task, which, however, sometimes requires the changing of part of the instrument. Receivers, diaphragms,

cords, zincs, and battery salts should be carried by the inspectors. The principal tools required by the latter are a small pair of cutting pliers, tweezers, a medium-sized and a small screw-driver; a pad handle, with loose bradawls, gimlets, a receiver gauge, etc.

Intermittent Faults.—The faults spoken of above may be called *lasting* or *complete* faults, which exist continuously until rectified. The faults which often give far more trouble to locate are those which come on occasionally, and last but a short period, the instrument working in the intervals perfectly well. Such faults are often very difficult to discover, as there is nothing definite to work upon. The chief thing is to make inquiries as to the circumstances under which the fault is observed, and how it affects the working, and from the answers obtained form some conclusion as to what part of the instrument or line is affected, after which a close search for loose contacts, bad joints, broken wires, etc., must be made. The telephone cord frequently causes intermittent faults by the tinsel conductors becoming broken, or by part of the tinsel of one conductor piercing the worsted covering, and coming into contact with the other conductor, causing a short circuit. This fault may usually be detected by putting the receiver to the ear, and then continuously blowing on the transmitter, while with the other hand the cord is pulled, twisted, and moved in different ways. If the fault is in the cord, this movement will cause the noise of blowing to cut off every now and again. An even better method is to connect the cord and receiver to a cell direct, and then listen while the cord is bent about. Faults, if present, give rise to clicks or spluttering sounds, as they act like microphones.

Those intermittent faults which occur on windy days may be put down to the line, as they are most likely due to a loose joint in the wire, a broken conductor in the leading wires, or are caused by the wire itself swinging against some earth connection.

Two inspectors are often required to locate a fault of this kind, one at each end of the line.

Most Common Faults.—Many of the defects which crop up in connection with instruments have already been mentioned. Below will be found a list of the most common faults.

Receivers.—*Cores too near diaphragm,* not allowing sufficient space for vibration. This is often caused by the receiver being dropped. It may be remedied by carefully knocking back with a hammer. This fault should not occur with a properly designed receiver.

Diaphragm buckled, often caused by users poking with pencils. A new diaphragm is often required.

Packing ring lost or in wrong place, caused by subscribers taking off the cap.

Dirt between Cores and Diaphragm.—Already referred to.

Bad soldered connection between the terminals and the wires leading to the coils, causing an intermittent fault. This may be detected by pressing in different directions on the terminals while listening, and blowing on the transmitter; or by connecting direct to a battery and listening with the receiver.

Loose bobbins.—*Weak magnet.*—The cures for these faults will be evident.

Transmitters.

Damaged Carbon Diaphragms.—Being very thin, these are very liable to be punctured or cracked, thus allowing the granules to escape.

Faulty connections to carbon plates sometimes occur.

Wire gauze pressed on to diaphragm by poking with pencils.

Carbon granules escape from under felt, or are clogged together.

In replacing the lost granules great care should be taken that the proper grade is used and that they are uniform in size with the particles left in the carbon cell.

Induction coils short-circuited or disconnected.

Frying Noises.—A common source of trouble with granular transmitters is a kind of frizzling or frying noise which is very

annoying. It is often caused by too much current burning up the carbon granules, or may be due to loose connections in the primary circuit.

MAGNETO BELLS.

Short circuits are sometimes caused by particles of brass ground off defective driving gear.

Automatic switch lever sticking, and not making proper contact for speaking when receiver is removed. Spring should be strengthened, the lever taken off, and pivot cleaned and rubbed with black lead, as also any springs which bear upon it. No oil should be used on lever, as it will hold dust, thicken, and spoil the connection. Black lead is much more satisfactory than oil as a lubricator in these cases.

Bad contacts on lever can be cured by scraping and rubbing with black lead, as above.

Weak polarising magnet should be replaced.

Gongs out of adjustment.

Lightning arrester plates short-circuited, caused, perhaps, by loose nails, pins, etc., lying across.

Generator cut-out and collecting springs weak, and not making proper contacts. Should be taken off, and bent, to give harder pressure.

BATTERY SWITCH-BELLS.

Bad Contact on Telephone Lever.—See above.

Faulty contacts on local contact springs caused by dust.

Trembler bell contact faulty, causing a break in ringing circuit. Caused by dust, or by the adjusting screw being loose or not bearing on the platinum contact. A clamping nut or screw should always be used to tighten the adjusting screw.

Residual magnetism, causing a break by attracting the armature, and keeping the spring from the contact pin.

Faulty contact against back stop of ringing key.

BATTERIES.

Cracked cell, allowing the solution to run away.

Corroded, loose, or dirty terminals or wires.

Faulty connection of wire to zinc rod or cylinder.

Faulty connection between terminal and carbon.

Exhausted solution, shown by crystals forming on zinc and porous pot in wet cell.

Zinc rod consumed.

SWITCH-ROOM FAULTS.

Indicators sticking, owing to binding at pivots preventing armature moving, or to the shutters being too upright, so that they do not fall over when released. A little bending over will generally remedy the latter fault.

Bad contacts in spring-jacks, caused by dust. By means of a thin steel spring, provided with a handle, and roughened by being cross-filed with a coarse file, the contacts in the jacks may be cleaned from the front of the switch-board.

Bad joints, due to defective soldering.

Dust on the back contacts of ringing and listening keys.

TABLE OF SUB-STATION FAULTS PER MONTH PER 1000 STATIONS

	No. of Faults		No. of Faults
PRIMARY CIRCUIT		BELL CIRCUIT	
Faulty battery wires .	1	Generator springs faulty	3
Cells exhausted . .	14	Armature sht.-cirtd. .	·5
Carbon granules clogged	1	Bells out of adjustment .	3
H. M. contact spring faulty . . .	1	Bell armature demagnetised (Ericsson) .	2·5
Primary coil sht.-cirtd. .	1	Bell coil dis. . . .	·5
Carbon diaphragm broken . . .	·5	MISCELLANEOUS	
SECONDARY CIRCUIT		Window and other terminals . . .	2
		Office wire . . .	2
Switch-hook faulty .	2	Lightning arresters .	·5
Connecting cords do. .	5	Auxillary apparatus, switches, etc. . .	7
Receiver coils do. .	·5		
Receiver magnets do. .	1	Other faults . . .	2
		GRAND TOTAL .	50

Table of Instrument Faults.—In order to give some idea of the relative frequency of the different faults in connection with sub-station instruments, a table is given above showing the number of such faults per month per 1000 instruments in an important provincial exchange. The system in use was magneto ringing, with (mostly) wet cells for the local transmitters, these having replaced the dry cells which had been hitherto used, being found more reliable, especially when a six-monthly system of inspection is employed.

Faults in Common-Battery Instruments.—The foregoing remarks apply more particularly to the faults in connection with magneto-signalling and local-battery instruments, but most of the statements apply equally to C.B. instrument faults. The latter instruments consist of fewer parts, and are, as a rule, constructed in a very substantial manner, so that faults are much reduced. The tracing of faults in such instruments is also simplified, as, if the line wires are in order, there will be a current available for testing the different parts, so that, for example, in the case of a disconnection, it will only be necessary to connect a galvo or receiver in the circuit at the window terminals, and then to successively bridge over the parts with a piece of wire until the battery circuit is complete. To trace a short circuit, the connections are broken one by one until the current ceases.

A source of trouble with C.B. sub-stations is in connection with the leading-in wires, where they have been stapled on damp walls, and are not in themselves of a good insulating quality. This is especially the case when a magneto system has been converted to C.B. working without renewing the leads, the constant voltage on the lines soon resulting in trouble. Another trouble when an exchange is being converted to C.B. working is caused by the receivers being wrongly joined to the line, so that the current neutralises that polarity of the cores which is due to the inducing effect of the permanent magnets, thus making the received speaking very weak. This can be detected by reversing the cord connections, and so finding which connection gives the better speaking results.

LINE FAULTS.—When faults are traced to the line, they are handed over to *linesmen*, whose duty it is to find the causes, and remedy them, and who should be perfectly familiar with the various routes and the wires upon them.

Line faults come under three principal headings: 1. *Contacts* between different lines or between the two wires of a loop. 2. *Earth faults*, caused by wires coming into contact with some conductor connected to earth through more or less resistance. 3. *Breaks*, either total or partial, caused by bad joints or a fracture in the line or leaders at some point.

(1.) In tracing contacts it is generally possible to find out what wires are in contact, and, knowing this, the linesmen can often walk at once to the point, as they may know that the lines can only come together at one point where their routes meet.

When the position cannot be so ascertained, a linesman will walk over the route of one of the lines, or both, if they run together, and carefully scrutinise the wires as he goes along. By so doing he will probably come to the seat of the trouble. If the contact cannot be found in this way, it becomes necessary to disconnect one of the wires at some point, and then make a test from the other end, to discover if the contact has disappeared. If it has disappeared, the contact must be farther away from the testing station, and, the wire being again joined up, other breaks are made farther along, until the linesman arrives at a point where the contact does not disappear. The fault will then lie between the two last disconnections. On long trunk lines test-boxes are fixed along the route, into which the lines are led by covered wires, and attached to double terminals, so that tests may be easily made.

(2.) *Earth Faults*.—The procedure followed in tracing an earth fault is much the same as for a contact.

(3.) *Breaks*.—If a line is broken down, the linesman walks over the route until he comes to the broken span. On long lines, and when the fault is a difficult one to find, an earthed battery is connected to one end of the broken line, and the linesman from time to time connects the faulty line to earth

through his galvo, and notes if he gets an indication of the current on the line. When he has passed the break the deflection will not be obtained.

For *partial breaks*, when the wire shows a very high resistance, the same procedure may be followed. A much

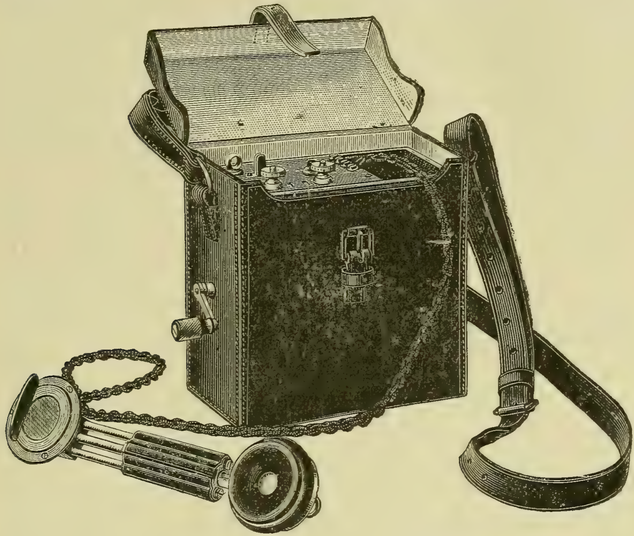


Fig. 413.—Portable Test Set

weakened deflection will then be obtained when the fault is passed.

Intermittent line faults are a source of great trouble in locating, as in the case of similar instrument faults.

Such faults are readily detected in C.B. exchanges, as momentary earth contacts which would scarcely be noticed in a magneto exchange will actuate the signals every time the contact occurs, and the operator at once reports to the test-clerk for further testing.

Portable Testing Sets.—Linesmen should be provided with a light testing set, such as that shown in Fig. 413. This set, made by the Ericsson Co., weighs only $8\frac{1}{4}$ lbs., and comprises

telescopic hand-micro magneto bell, generator, two small dry cells, shoulder strap, and outer leather case for protection. The connections are as shown in Fig. 414.

Inspections of Instruments.—In order to ensure that the instruments are kept up to a proper state of efficiency, it is necessary that there shall be regular systematic examinations of all sub-station instruments, batteries, etc., by special inspectors. These should be carried out at least twice during the year. Any parts found defective must be put in good working order or reported for changing, and a record should be

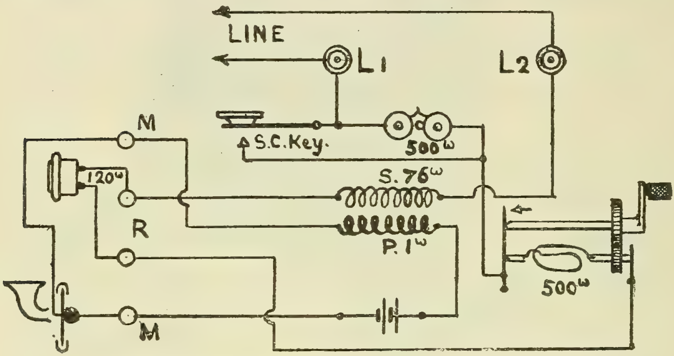


Fig. 414.—Connections of Portable Test Set

made of the date of inspection and the condition, for which purpose special cards are provided for each instrument, one such being kept at the instrument and another at the exchange, where they are kept in numerical order in a proper card-index file, so that any one may be readily available, and the record of the instrument seen.

Switch-Board Tests.—All the apparatus in connection with switch-boards should also be periodically tested, but at much shorter intervals than with the sub-station instruments. As such tests are troublesome to make during working hours, arrangements are usually made to utilise the night-service men to make the tests, and special instructions are issued for a certain number of drops, lamps, cords, junction lines, sub-

scribers' lines, operators' keys, etc., to be systematically tested each night, so that the whole may be got through in about a week's time. If possible, the faults found are rectified by the night men, but if this is not feasible reports are made out, which are handed the next morning to the day inspectors for attention.

In discovering and localising faults on switch-boards only simple apparatus is necessary. The faults that most frequently occur are disconnections, short circuits, contacts between wires of other lines, and earth connections. As in the case of sub-station instruments, intermittent faults give the greatest trouble. Keen observation will, as before mentioned, often at once localise a fault, which may be caused in the simplest manner, such, for example, as by the careless leaving about of chains, etc., by the operators.

Jack faults are not so easy to discover, as the seat of trouble will be out of sight, and, in the case of multiple boards, will need to be localised to some particular section of the board. If the fault is a *break in the line*, it is easy to localise, by connecting a buzzer with battery in the apparatus-room to the loop affected, and then inserting a solid metal plug into successive multiple-jacks of the line, beginning with those nearest to the apparatus-room, until the buzzer fails to sound when the plug is inserted. The fault would then lie between the two last jacks tested. This test applies equally to boards with break or branch-jacks.

If the fault is a *short circuit or earth* the procedure would be similar to that last described if the board is of series break jack type, except that the plug employed would be an insulating plug. The sound of the buzzer, however, in this case would be cut off when the plug was inserted in a jack until the fault was passed, when the insertion of the plug would not interrupt the continuous sounding of the buzzer. For an earth fault, the test battery would have one pole connected to earth, but the procedure would be the same.

Branching-Jack Faults.—The most common method of localising short circuits, contacts, and earths on branching-jack

boards is based on the *fall of potential* method. A battery is connected in the apparatus-room to the two wires affected (or one wire and earth), and then a receiver, fitted with two single cords and plugs, is connected to two points of one of the faulty lines by plugging into the proper jacks at adjoining sections. If the receiver so connected is between the battery and the fault, a click will be heard in the receiver each time a plug is tapped in or out of a jack, as, owing to the resistance of the line, there will be a potential difference between the two points. If, on the other hand, the connections are made on the other side of the fault, no click will be heard, as there will be no P.D., all this part of the wire being at the same potential. The plugs should only make contact with the receiver on one spring of the jacks. The above will be better understood by reference to Figs. 415 and 416 and description.

One of the wires affected may be the test or click wire, or it may be a wire of another loop in contact, the procedure being in each case similar, and readily understood.

There are several other methods of localising the above faults, such as by testing the lowest resistance of the loop at various points of the board, or by the loop test with a Wheatstone bridge, as described in the next chapter, but the above described are considered the simplest and most reliable methods.

See next chapter for "loop" tests for faults and for testing by voltmeter.

CHAPTER XXIX

ELECTRICAL MEASUREMENTS

The electrical quality of the materials employed by telephone companies is of great importance to efficient working, and it is therefore necessary that their resistance, capacity, leakage, etc., should be determined, and that tests be periodically made to ascertain what deterioration has occurred.

To make such tests and measurements more accurate instruments than those mentioned in Chapter XXVIII. are required. Every large centre where a number of trunk or junction lines or cables are connected should, therefore, be provided with a set of testing instruments, comprising at least (1) a Wheatstone bridge, with resistance-box; (2) a reflecting galvanometer of high sensibility, with shunt-box, lamp and scale, and short-circuiting key; (3) a standard condenser of about ½ microfarad capacity; (4) a well-insulated discharge key; (5) a battery reverser; and (6) a battery of at least 50 cells. These instruments will be very briefly described, and their uses explained.

The *Wheatstone bridge* is one of the most generally useful of testing instruments. It is based on the principle that when a current passes through a conductor the potential falls (or rises) in exact proportion to the resistance passed through. Suppose, for example, a current is sent through a uniform wire of 20 ohms resistance, as A B in Fig. 415, and the potential at A is 8 volts and at B is 0, being connected to earth (the potential of the earth is taken as zero for ordinary purposes), then the total fall of potential is 8 volts, and the rate of fall may be represented by the slant of the line *a b*. At the middle point of the wire the potential

would be 4 volts, showing a fall of 4, which is one-half the total fall. At a quarter the length or resistance from A the fall would be $\frac{1}{4}$ of 8, and so on, in exact proportion to the resistance. If a second conductor were joined between the points A and B, the total fall would be the same along either of them, as would also be the case at points $\frac{1}{4}$, $\frac{1}{2}$, or $\frac{1}{3}$ of the total resistances respectively from A to B. If corresponding points in the two wires were connected by a third wire forming a bridge, it would be found that no current would pass through it, because there would be no *potential difference* to produce

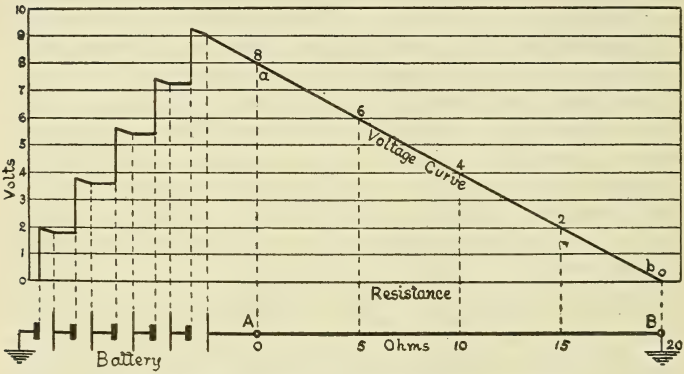


Fig. 415.—Diagram showing Fall of Potential

a current. No current, in fact, would pass through a bridge between *two points in two conductors* (*joined at the ends*) *dividing them into the same proportional resistances.*

Fig. 415 shows how the voltage rises in a battery of five cells each of an E.M.F. of 2 volts, and also shows the fall in each cell due to its internal resistance. The negative pole of the battery and the "B" end of the wire are shown connected to earth, which is taken as at zero potential.

In the practical instrument a galvanometer is used as the bridge, and the more sensitive this is the more accurate the test can be made. The bridge and resistances are usually represented as in Fig. 416, C L E representing one conducting-

path, made up of a known resistance, *b*, and an unknown one, *x*, and C G E representing the other conducting paths, made

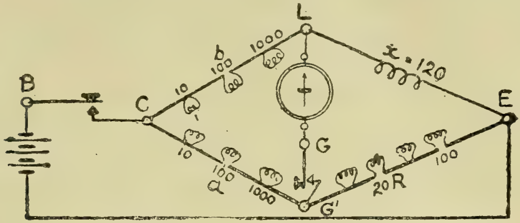


Fig. 416.—Skeleton Diagram of Wheatstone Bridge

up of *a*, a known resistance, and R, an adjustable resistance. The battery key B is provided so that the battery may be connected when required, and the key G (which should be

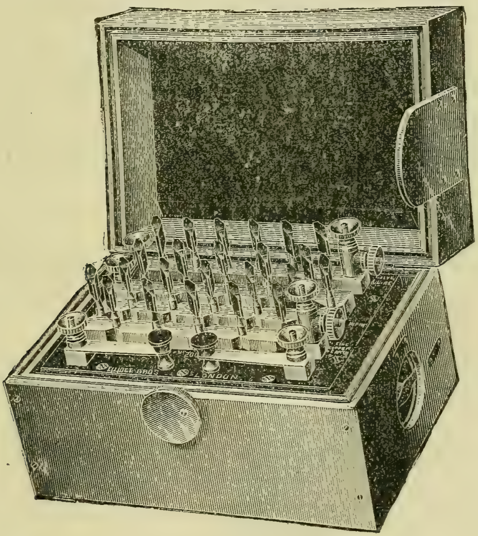


Fig. 417.—Post Office Pattern of Wheatstone Bridge

depressed *after* the battery key) is used to prevent the dis turbance which would otherwise be caused by self-induction when an electro-magnet or ordinary coil was being tested.

Fig. 417 shows the most convenient practical form, known as the Post-Office pattern, and Fig. 418 is a plan of a similar one, showing also the connections for measuring an ordinary resistance. The ends of resistance-coils underneath are connected to thick brass blocks which, by means of slightly-tapered brass plugs, can be connected together so as to short-circuit the resistances. The numbers represent the values of the resistances, and the lettering is the same as in Fig. 416.

On depressing the battery key B, Fig. 418, the current passes

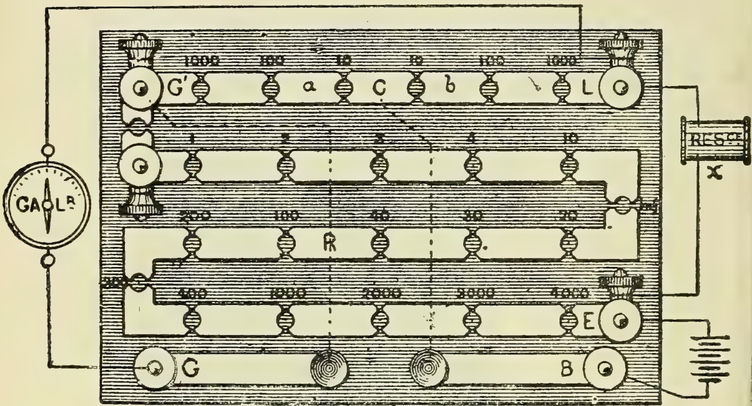


Fig. 418.—Plan of Wheatstone Bridge

by connection below (shown by dotted lines) to C, where it splits, one path being through the unplugged coils on the right, and through the resistance to be measured x, to terminal E, and the other path being through the left-hand unplugged coils, and those unplugged in the adjustable arm R to terminal E. The galvanometer is bridged in between G′ and L when key G is depressed. The resistances in the adjustable arm are altered until, on depressing B and G, no deflection is observed, this being the case when $a : R = b : x$. Three of these quantities being known, it is easy to find the fourth, as $x = \frac{bR}{a}$. If the arms a and b

(Fig. 416) are made equal, as is generally the case, the unplugged resistance in R will equal the unknown resistance.

By unplugging 10 on the left and 1000 on the right of C on the top row, the resistance unplugged in R will balance a resistance, x, 100 times as great, so that the total resistance in R of 11,110 ohms will balance an x resistance = 1,111,000 ohms, or over 1 megohm. On the other hand, by having 10 ohms on the right and 1000 on the left of C, a resistance as low as ·001 of an ohm can be measured, although the smallest resistance in the instrument is 1 ohm.

By varying the ratios of the resistances on the two sides of the top arm, any resistance between the extremes mentioned may be balanced; but most frequently the ratios are equal—the two 1000-ohm coils being used when measuring a high resistance, and the two 10-ohm coils when measuring a low resistance.

The advantages of the Wheatstone bridge in testing are that any galvanometer can be used in connection with it (but the more sensitive the better); that the result is independent of the resistance of the battery or galvanometer, and that but few resistance coils are needed to measure resistances within a large range.

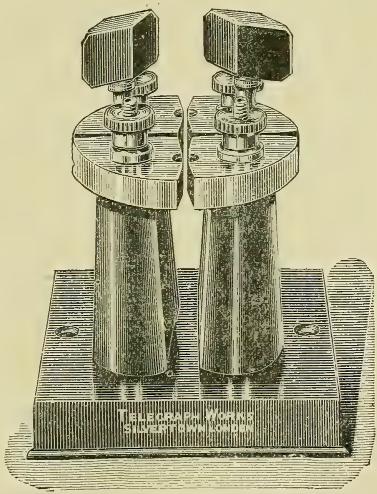


Fig. 419.—Pillar Battery Reverser

When one end of the resistance to be measured is far away, and no return wire is available (which is seldom the case in these days of metallic circuit lines), the earth must be used as a return—an earth connection being then put on terminal E. If, however, another wire is available whose

resistance is known, it is much better to make up a loop circuit with it, as an earth return introduces errors due to faulty earth connections and earth currents. The latter can be eliminated by making a second test with a reversed battery connection, and taking the mean of the two results. The instrument shown in Fig. 417 is provided with a battery reverser, seen on the right, for this purpose. A simple and well-insulated battery reverser for separate use is shown in Fig. 419, it being constructed of four brass quadrant blocks supported on four ebonite pillars. Fig. 420 is a plan of the quadrants, with connections. By altering the two plugs shown from the holes in *one diameter* to those in another the connections are reversed.

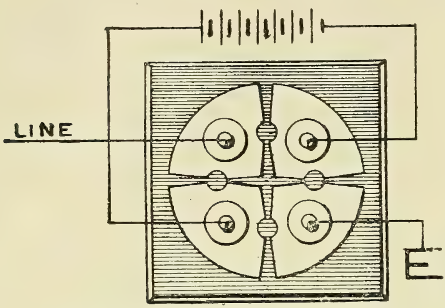


Fig. 420.—Plan of Battery Reverser

The Loop Test.—It is often of much importance to be able to ascertain the distance of a fault on a trunk or line, so that a linesman may be at once sent to the spot without his having to walk along many miles of the route in search of it. This can be readily done if the fault is an earth connection, and if but one wire of the loop line is affected. If both wires are faulty, it is necessary to use a second good wire to form a loop with one of the faulty wires.

Fig. 421 shows the connections required, differing only from Fig. 416, it will be seen, in having the carbon end of the battery taken off and put directly to earth. It may be necessary to reverse the line connections before a balance can be obtained, in order to get the faulty wire on terminal E. Supposing the top arm ratios are equal when a balance is obtained, we shall have the resistance of the good wire plus the far part of the

faulty one (y) equal to the resistance of the near portion of the faulty wire (x) plus the unplugged resistance in the adjust-

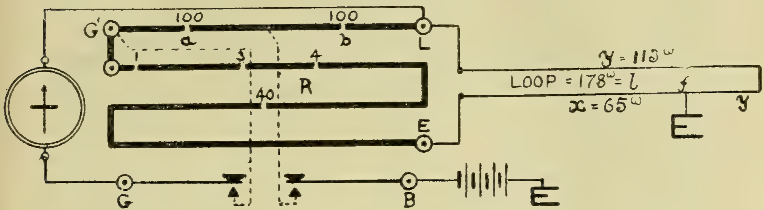


Fig. 421.—Connections of Wheatstone Bridge for Loop Test for Leakage Fault

able arm (R). Knowing the resistance of the loop (l), or measuring it in the ordinary manner, we shall then have

$$\text{From } y = x + \text{R} \text{ and } l = x + y$$

$$\text{we have } x = \frac{l + \text{R}}{2} - \text{R} = \frac{l - \text{R}}{2}$$

$$\text{With unequal arms } x = \frac{al - b\text{R}}{a + b}$$

The resistance obtained, divided by the resistance per mile of the wire, will give the distance to the fault in miles.

The great advantage of the loop test is that it is quite independent of the resistance of the fault itself; if the latter

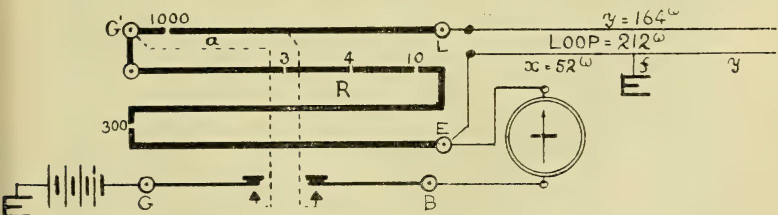


Fig. 422.—Connections for Loop Test. Alternative Form

is high, however, it becomes necessary to use a strong battery in order to obtain reliable results.

Fig. 422. shows another plan of loop test which is sometimes preferred, or may be used to check the figures arrived at by the first plan. In this the connections of the galvanometer

and battery are exchanged, so that the current splits from the terminal G instead of C, and the right-hand set of resistances in the top arm are kept plugged up. When a balance is obtained, the unplugged resistances on each side of G are to each other as the two portions of the loop divided by the fault, or $a : R = y : x$. From this and $l = x + y$ we get $x = \frac{lR}{a+R}$, and $y = \frac{al}{a+R}$.

Actual examples are shown in Figs. 421 and 422, which may be used as exercises. The unplugged resistances are figured.

Loop Test for Contact.—Either of the loop tests given above may be used to localise the point of contact between two lines,

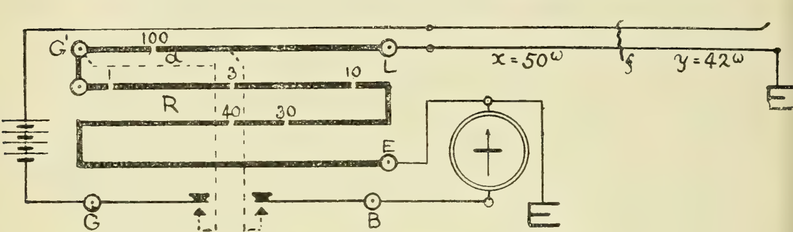


Fig. 423.—Connections for Loop Test for Contact

if a loop can be formed with a faulty wire and a good one, and if the other line in contact can be put to earth. If such a loop cannot be formed the lines may be joined up as shown in Fig. 423 one of the wires in contact being joined to the battery, as shown, the other end being disconnected, and the far end of the other wire earthed, as shown. The other connections and calculations are the same as in the last loop test, but x and y must now be considered as the near and distant portions of the same wire.

If the contact offers no appreciable resistance, half the resistance of the loop formed by the near portions of the two wires in contact will give the resistance to the fault if the wires are of similar size and material, but it is seldom advisable to rely on such a test.

Insulation Resistance.—This is the measure of the resistance of the insulating materials, or the surfaces of these materials, used to confine the current to the required path through the line. With a covered wire the insulation leakage which occurs is due to the current which actually leaks through the whole of the insulating material, but in the case of bare overhead wires the leakage is only at the points of support, and is generally a matter of leakage over the surface of the insulating cups, through moisture or dirt, or both, deposited on their surface. The leakage of an open line is made up of more or less uniform losses at numerous supports, and the resultant resistance is a combined resistance made up of the resistances of a number of insulators joined in branch or multiple. If the resistance

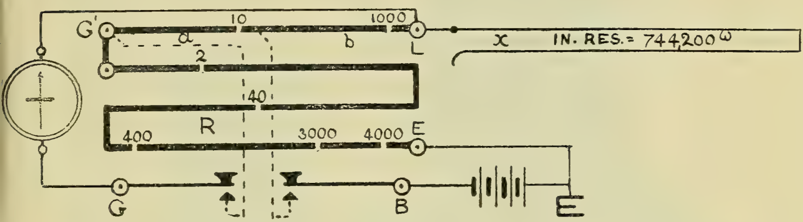


Fig. 424.—Connections of Wheatstone Bridge for Insulation Test

of each insulator be taken as 100 megohms, then the insulation of a line having 200 supports (about $7\frac{1}{2}$ miles of single line) would be $\frac{100}{200} = 0{\cdot}5$ megohms $= 500{,}000$ ohms. The conductivity resistance of the wire itself between the points of leakage is so small in comparison that it may be neglected.

The insulation resistance may be measured by means of the Wheatstone bridge when the total resistance does not exceed 1,111,000 ohms (1·111 megohms). Fig. 424 shows the arrangement necessary. One end of the line is connected to terminal L, and the other end is insulated. Terminal E and one pole of battery are joined to earth, and it will usually be necessary to unplug the 1000 ohms resistance in *b* and the 10 ohms in *a*, the balancing resistance in R being then multi-

plied by 100 to get the *absolute* resistance. The number thus obtained, *multiplied* by the length of the line in miles, will give the insulation resistance per mile of the wire. It will be necessary to use a strong battery for this test, and the galvanometer used should be a sensitive one.

Mirror Galvanometer.—For measurements of high insulation, and for making very accurate tests, it is necessary to employ a *reflecting* galvanometer such as the *Kelvin Astatic Galvanometer.*

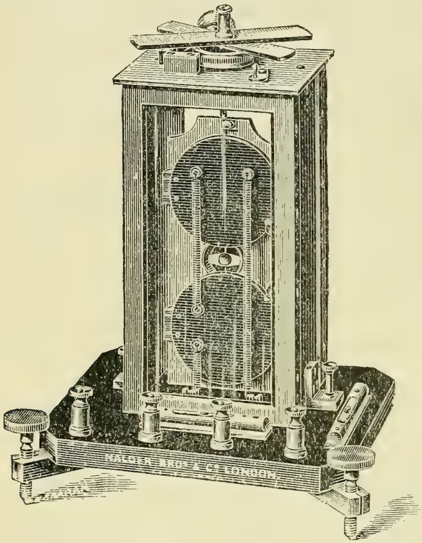


Fig. 425.—Kelvin Mirror Galvanometer

A very good form of this, made by Messrs Nalder, is shown in Fig. 425. It consists of four fine wire coils hinged to an upright brass plate, two at the top and two below, so as to form, as it were, two larger coils, the whole being wound to about 6000 ohms. Within these coils are suspended, by means of a fibre of raw silk, two sets of very small magnets, one in each coil, each set being cemented on the back of a circular disc about $\frac{3}{8}$ inch in diameter, an aluminium vane intended to steady the movements being connected to the combination. The two sets of magnets are rigidly joined together in the same plane, but so that the north poles of the top set are over the south poles of the lower set, this forming an *astatic* combination, by means of which the earth's action is neutralised. In the centre between the two double coils is an opening, in which is a small glass mirror fastened so as to move with the magnet needles. The coils are so joined

up that a current passing through all, tends to turn the combination in the same direction. The terminals of the instrument are fixed on an ebonite base, fitted with spirit levels and levelling screws, and the coils, etc., are covered with a case having glass sides. On top of the instrument is a pair of "scissors" adjusting magnets, by means of which the astatic system can be very readily directed, and the sensibility altered.

About 3 feet away from the front of the instrument is set a

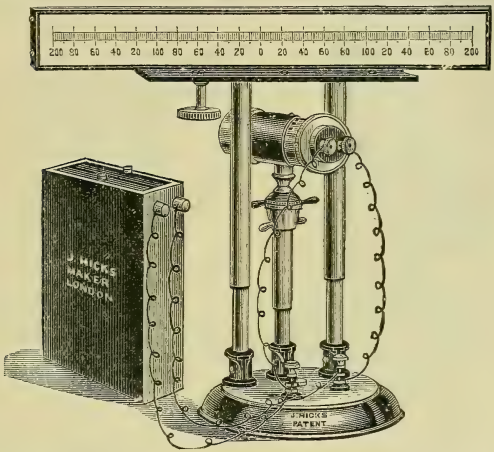


Fig. 426.—Lamp and Scale for Kelvin Galvanometer

lamp, supported on a stand furnished with a graduated screen. A hole in the centre of the stand is furnished with a brass tube, in which a lens is fitted. Through the latter a beam of light is made to fall on the mirror in the galvanometer, from which it is reflected on to the graduated screen. An image of a fine vertical wire, fixed close to the lamp, is focussed on the screen, and enables the readings to be taken very accurately.

Fig. 426 shows a very convenient lamp and scale. With this an incandescent electric lamp is used, and the scale is printed on a translucent screen, so that the spot and line can be ob-

served from either side. The screen is adjusted by means of a rack and pinion.

Fig. 427 shows a somewhat different arrangement of the Kelvin reflecting galvanometer made by Nalder Bros., in which the outer glass case is dispensed with, so that it can be made considerably cheaper, although equally convenient and sensitive. It is also provided with "scissors" magnets for adjustment. The mirror is fixed between the two sets of needles and coils, and is protected by a glass lens.

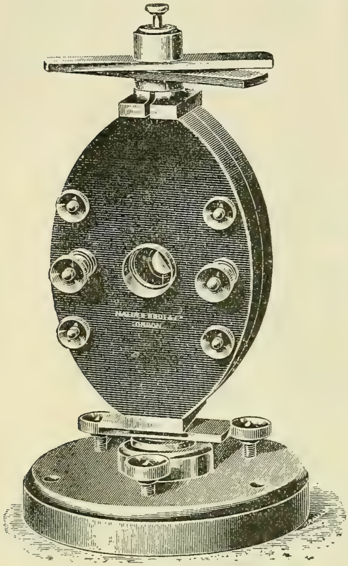


Fig. 427.—Simple Form of Kelvin Galvanometer

A mirror galvanometer must be kept very steady, as the slightest jar will set the mirror quivering, so that readings cannot be taken. For this reason, the instrument is usually placed on a heavy slab of stone, which rests on india-rubber blocks set on a structure built into a solid wall.

The advantages of the Kelvin instrument over the ordinary form of galvanometer are that the turns of wire can be brought very near to the needles, and so act powerfully on the astatic system, and a shorter length of wire is required for the same number of turns. The beam of light also forms a very long and weightless index, which moves twice as far as an actual fixed index of the same length, by reason of the law of reflection.

D'Arsonval Galvanometer.—This is a reflecting instrument which to a large extent has displaced the Kelvin galvanometer for many purposes. It is very convenient owing to its *dead-beat* action (which means that the deflection is made

direct to the proper point on the scale without unnecessary vibration about that point) and its freedom from the effects of external vibration and magnetic influences. It is not, however, so sensitive, and has not the all-round usefulness of the Kelvin instrument. Fig. 428 shows its construction. Between the poles of a strong compound horseshoe magnet is fixed a soft-iron cylinder, which serves to direct the lines of force, and in the space between this and the poles of the magnet a rectangular coil of wire, with mirror attached, is suspended by a very thin silver wire at top and bottom, these

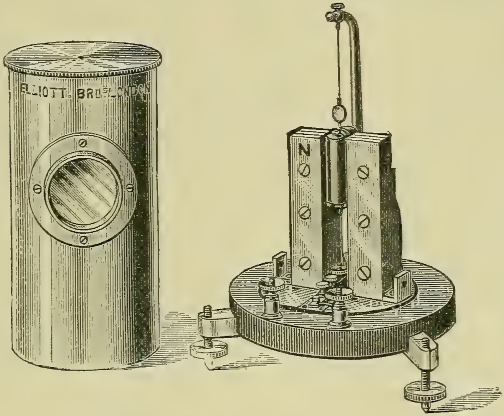


Fig. 428.—D'Arsonval Galvanometer

wires also serving as connections to the coil. A spring at the bottom and torsion screw at top serve to adjust.

When a current passes through the coil the latter is deflected to one side or the other, the coil tending to set itself at right angles to the line joining the poles, so as to embrace the greatest number of lines of force, but having its deflection restricted by the torsion of the suspending wire. The figure shows the instrument with its cover removed. The coil is usually wound to about 750 ohms.

Shunts.—As these reflecting instruments by themselves would be much too sensitive for many purposes, a set of

shunts is used with them, by means of which the sensitiveness may be reduced to $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$, by diverting $\frac{9}{10}$, $\frac{99}{100}$, or $\frac{999}{1000}$ of the current from the galvanometer. A plan of the top of such a *shunt-box* is shown in Fig. 429.

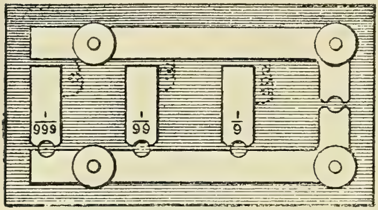


Fig. 429.—Plan of Shunt Box

The shunts are marked $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$, these being the fractions of the resistance of the galvanometer required for the $\frac{1}{10}$, $\frac{1}{100}$, and $\frac{1}{1000}$ shunts respectively.

The shunts are inserted by plugging in between the brass blocks, and the instrument itself and galvanometer can be short-circuited by a plug inserted as S C, so as to prevent damage by accidental currents. A much more convenient method of doing this, however, is by means of a separate *short-circuiting key*, which is simply a well-insulated spring key with a top contact, and an ebonite catch to fasten down the spring when not required. By proper manipulation of this key the readings of the deflections can be very quickly taken, and much time saved, one reason for this being the elimination of the throw of the needle, caused by the capacity of the wire under test when the battery connection is first made.

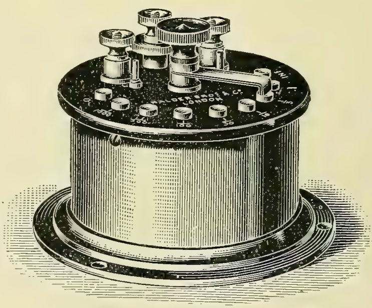


Fig. 430.—Universal Shunt Box

Universal Shunt. — Of the shunt-boxes described, any one box can be used only with the galvanometer for which it was specially made, or with one of exactly the same resistance. A special shunt-box has been devised by Messrs

Ayrton & Mather, which has the advantage that it can be used with *any* galvanometer. Fig. 430 shows a rotary switch form, and Fig. 431 the plan and connections of a peg switch form of the instrument. G is the galvanometer, and R a resistance which can be permanently connected to the terminals. By means of a plug or circular switch, one of the line leads can be connected to a point $\frac{1}{10}$th, $\frac{1}{100}$th, or $\frac{1}{1000}$th part of the resistance of R, and the current passing through splits into proportional parts, one part going only through the fraction of R, and the other part passing through the remaining fraction of R and the galvanometer. The resistance of R may be any quantity.

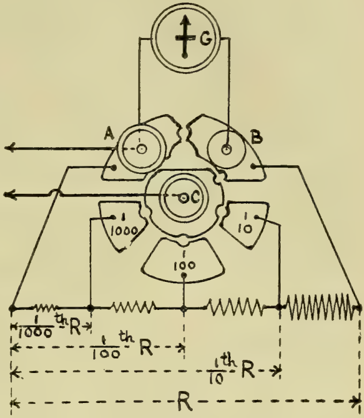


Fig. 431.—Connections of "Universal" Shunt Box

Among other advantages, this form of shunt is not affected by variations of temperature.

Galvanometer Constant.—The reflecting galvanometer is used to measure all very high resistances and very feeble currents. In order to make these measurements, it is necessary to first obtain the *constant* of the instrument. This, which expresses the value of the deflections, is obtained by joining up the instruments, as in Fig. 432 (which shows a galvanometer with the old form of directing magnet), the current being sent through a known high resistance, usually 100,000 ohms, the galvanometer being shunted so as to get a convenient deflection on the scale. If this cannot be done with the $\frac{1}{1000}$ shunt (which is usually the case), a part only of the battery, such as $\frac{1}{10}$th of the whole, should be used. The deflection being noted, it is multiplied by the shunt number **(10,**

100, or 1000). This will give the deflection which we may imagine would be obtained if it were possible to do without the shunts. This number is now multiplied by the resistance (as 100,000), and again by 10 if $\frac{1}{10}$th of the testing battery has been used. The constant so obtained (say, 50,000,000,000 ohms, or 50,000 megohms) will represent the resistance through which the testing battery will give a deflection of 1°. Dividing this number by any deflection obtained (allowing for the shunt), the quotient gives the resistance in the path of the battery.

Unless very accurate results are required, the resistance of

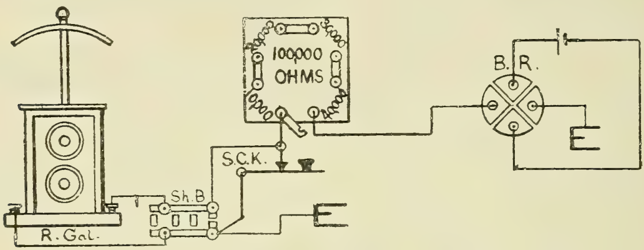


Fig. 432.—Connections for Galvanometer Constant

the galvanometer may be neglected, especially when the shunts are used.

Figure of Merit.—Dividing the constant as above by the voltage of the battery used gives a number which is called the *figure of merit* of the galvanometer, and represents the resistance through which 1 volt will give a deflection of 1 degree. The sensibility of galvanometers is in proportion to their figures of merit.

Fig. 433 shows the connections for making an insulation test of a cable wire. The resistance-box is short-circuited by a brass bar, and the wire to be tested put on at L in place of earth, the full battery being, of course, used. The opposite end of the wire must be carefully insulated. If the wire is in a cable the outer covering of the latter at the far end should be stripped off for about 4 inches, and the wires opened out from each other.

After the battery is connected to the wire, a minute is allowed to elapse before the reading is taken. This is for what is called the *electrification* of the cable wires, which is an effect due to a polarisation of the molecules of the insulating material, causing it to offer a greater and greater resistance to leakage, shown by a *steady* fall in the deflection. This fall is an evidence of good insulation, and is one of the principal points to be observed.

After the one minute's electrification the deflection is observed, and multiplied by 10, 100, 1000, according to the shunt used. The constant is then divided by this number, and the quotient is the insulation resistance of the wire. Suppose the constant is 50,000,000,000 ohms, or 50,000

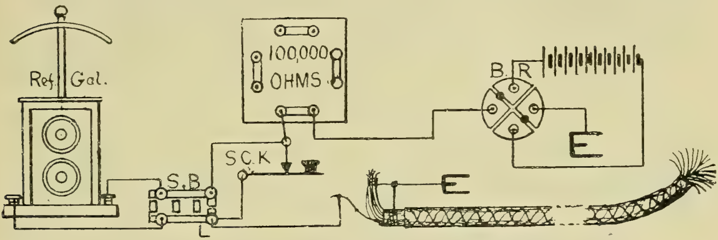


Fig. 433.—Connections for Insulation Resistance Test

megohms, and the deflection 560° (allowing for shunt), then $\frac{50,000}{560} = 89{\cdot}3$ megohms, is the *absolute* insulation resistance. The insulation resistance per mile, which is of even more importance, will be obtained by *multiplying* the absolute insulation resistance by the actual length in miles; or, if in yards, by multiplying by the number of yards, and dividing the product by 1760. For example, suppose the length of cable to be 1320 yards, or 0·75 mile, then $\frac{89{\cdot}3 \times 1320}{1760} = 89{\cdot}3 \times 0{\cdot}75 = 67$ megohms per mile of wire.

In testing cable wires it is usual to connect all the wires except that under actual test to earth. Where the wires are used to form metallic circuit lines it is usual to test them in pairs, the two ends being connected together on the one

terminal; in this case the *total* length of *wire* tested must be used in obtaining the mileage insulation.

Capacity Tests.—The evil effects of the storage or inductive capacity of wires, more especially of cable wires, upon telephonic currents has already been mentioned, and it is of much importance to ascertain the capacity of the wires in use. To effect this, in addition to a reflecting galvanometer, a *standard condenser* and a *discharge key* are required. Fig. 434 shows the former, which is a round brass box containing a large number of discs of tinfoil, each one laid between somewhat larger discs of thin mica. Every alternate disc of tinfoil is connected to one of the two terminals on the ebonite cover, and the remaining tinfoil discs to the second terminal, the two sets of tinfoil discs forming, as it were, the inner and outer coatings of a Leyden jar. The plug shown in the figure is used

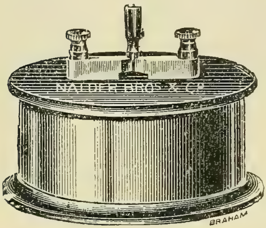


Fig. 434.—Standard Condenser

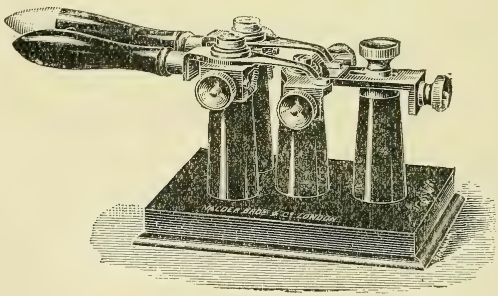


Fig. 435.—Rymer-Jones Discharge Key

to thoroughly discharge the instrument before use. An instrument of a capacity = 0·5 microfarad is a very convenient size.

Rymer-Jones Discharge Key.—A very good form of discharge key is shown in Fig. 435. Two brass levers with long insulating handles are pivoted to move horizontally on the

top of ebonite pillars. The end of each of the levers can make contact with a centre brass piece or with one side of a double contact plate. The centre contact is not generally used, and can be moved out of position. The long-handle lever is generally connected to galvo, through short-circuit key and shunt-box, the short handle to battery and the double contact plate to a plug switch for connection to cable, standard condenser, or standard resistance. The handles are moved to the left to charge, and to the right to discharge; and a small rod of ebonite fitted in one of the handles enables both to be moved together, and keeps the end of the levers from contact. Plans of two of these instruments are shown in Fig. 438.

The *Capacity "Constant"* is obtained as shown in Fig. 436, using another form of discharge key known as

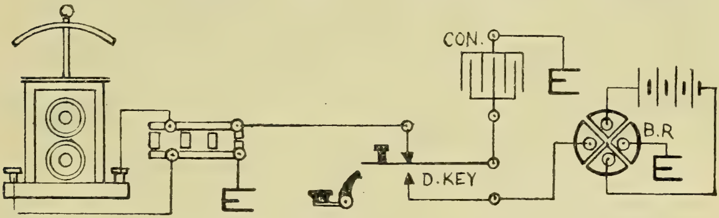


Fig. 436.—Connections for Capacity Constant

the "Kempe." The battery is connected to the bottom contact of the discharge key through the battery reverser. The lever of the discharge key connected to one terminal of the condenser is pressed down, and the condenser thereby charged. After about 15 seconds the "discharge" trigger is depressed, the lever springs up against the top contact, and the condenser discharges itself through the galvanometer, shunted, if necessary, to give a convenient deflection, which latter is only a momentary one. The short-circuit key must be kept open. Suppose the illuminated spot is thrown 720° by the discharge, this, divided by the capacity of the condenser, say 0·5, gives $\frac{720}{\cdot 5} = 1440°$, which would be the deflection given by 1 microfarad capacity. The deflections produced by other

capacities, divided by this number, will give the measure of those capacities. Thus, suppose a cable wire (with farther end insulated) joined up as shown in Fig. 437, gives a throw of 480° (allowing for shunt). This would show that the capacity of the wire was $\frac{480}{1440} = \cdot 333$ microfarad.

The *capacity per mile* will be the actual capacity of the wire *divided* by the length in miles; or, if in yards, the actual capacity, multiplied by 1760, and divided by the length in yards. Suppose, as before, the length of cable is 1320 yards,

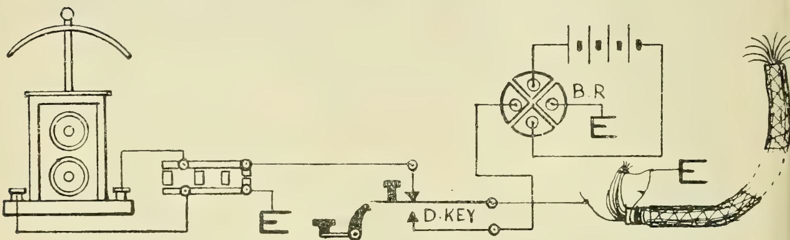


Fig. 437.—Connections for Capacity Test

or ·75 mile, then the capacity per mile shown by the above tests will be $= \frac{\cdot 333 \times 1760}{1320} = \cdot 444$ microfarad per mile of wire.

If a number of wires in the same cable are to be tested, then a *special* constant, obtained by multiplying the ordinary constant by the length of the cable in miles and fractions, is very useful. The discharge deflection of any wire divided by this special constant (or multiplied by the reciprocal of the latter, which is even more convenient) will give the capacity per mile of the wire tested. For example, the constant 1440 obtained above, multiplied by ·75 (the cable length), gives 1080, and this divided by 480, the deflection, gives ·444 as before. Working with the reciprocal of $\frac{1}{1080}$ $(= \cdot 000926) \times 480 = \cdot 444$. The advantage of the latter method is that, if a slide rule is used, one setting of the rule to the reciprocal is sufficient to give the

mileage results of all the wires tested in that cable. The capacity test of a wire should always be made before the insulation test, as the result might otherwise be affected by residual charges, due to the high voltage of the battery used for the insulation test.

For important tests it is necessary to make measurements, for both insulation and capacity, with reversed battery connections, taking the mean of results obtained in each case.

Loop Line Tests.—It is necessary in the case of loop lines to be able to find the actual insulation and capacity *between* the two wires forming the loop, as this is of more importance to the working than the insulation and capacity between the wires and the earth. To measure this it is necessary to have the two wires separated at the far end, to connect one wire of the loop to the testing instruments in the ordinary way, but to take any earth connection off the instruments, and *replace* it by the second wire of the loop.

It should be understood that all connecting wires used in joining up the instruments for tests of insulation or capacity must be of the highest insulation.

National Telephone Co.'s Test Set.—Fig. 438 shows a convenient arrangement of electrical measurement instruments, as used by the testing staff of the National Telephone Co. for insulation and capacity tests without altering the wire connections. A 3-point plug switch is used for connecting respectively to the cable, condenser, and a standard resistance. Two Rymer-Jones keys are fitted, a universal shunt-box and a combined battery reverser and short-circuiting key. Two cells are used for the capacity tests and the galvanometer constants, the other battery of 100 cells being used for the insulation tests.

Insulation Test.—The right-hand discharge key K′ is used for this, the *handles* of the left-hand key K being kept turned to the right. The handles of K′ are turned to the left for taking the constant, and to the right for the cable or line test.

Capacity Test.—For this test the handles of K′ are kept permanently to the left, while those of K are turned to the left

to charge, and to the right for discharge, the short-circuit key being opened in the interval between the two operations.

"Silvertown" Test Set.—This is a very convenient and compact bridge set, Fig. 439, which is much used in small

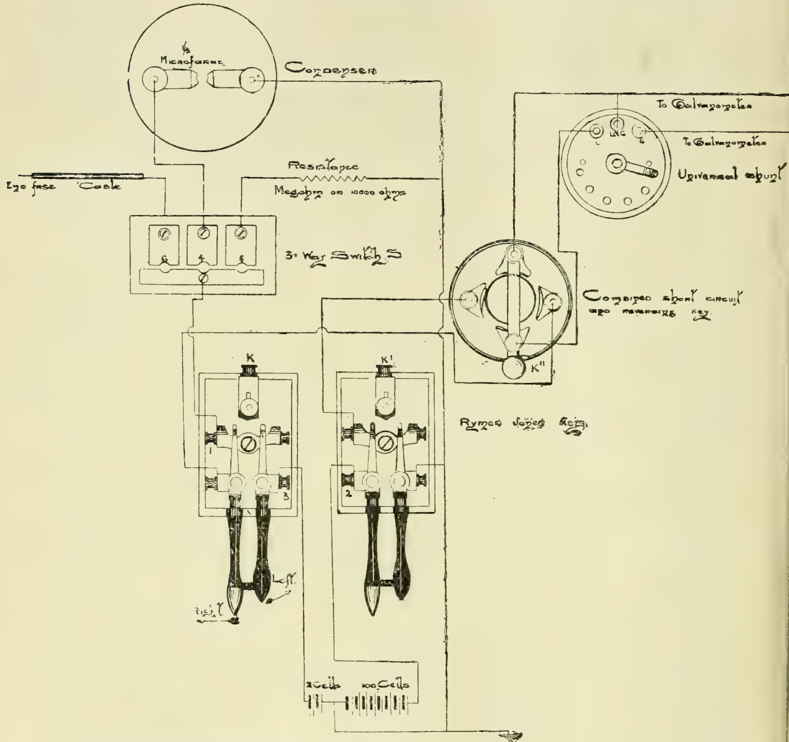


Fig. 438.—Connections of National Telephone Co.'s Test Set

centres where a more sensitive and expensive set could not be afforded.

Fig. 440 shows the inside connections, the lower part being the bridge and conductivity arrangement, and the upper part that used for the insulation test. The latter test is made by the "direct" method, as with the reflecting galvanometer.

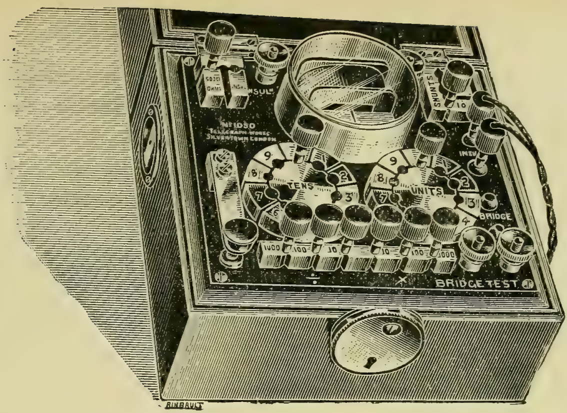


Fig. 439.—" Silvertown " Test Set

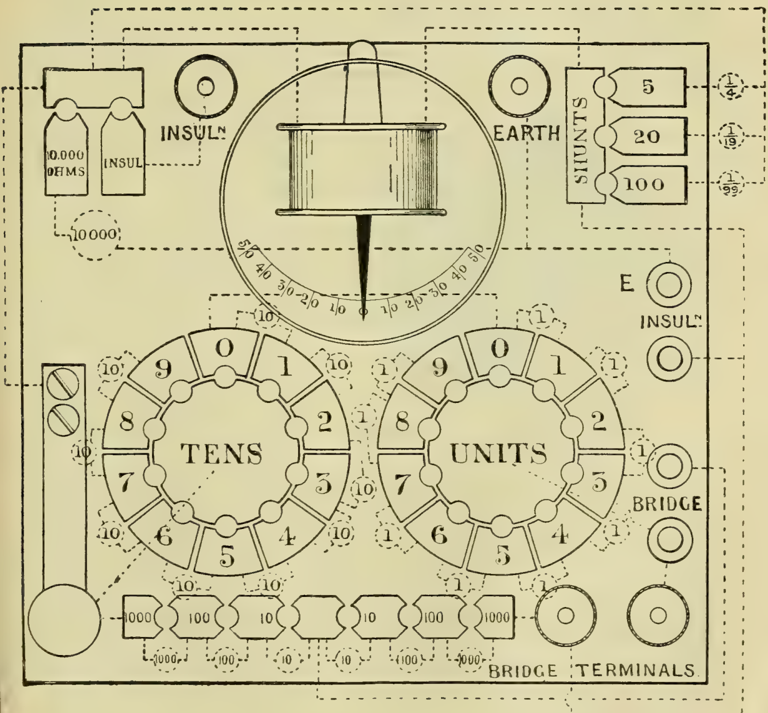


Fig. 440.—Plan and Connections of " Silvertown " Test Set

The battery of 36 cells for the latter test, and another of 3 cells for the conductivity tests, are connected by flexible cords and plugs to the terminals on the right, whilst the lines, or resistances to be measured, are connected to the terminals at the top and bottom. The adjustable resistances are arranged in circles, all in the "units" ring being of 1 ohm, and all in the "tens" ring 10 ohms each, the resistances being connected by the *insertion* of a single plug at each ring.

The box also contains a sensitive galvanometer, with $\frac{1}{5}$th, $\frac{1}{20}$th, and $\frac{1}{100}$th shunts, and on the left is fitted a plug switch for the connection of a standard 10,000 ohms resistance for the insulation constant.

The method of making the tests will be readily understood from the previous descriptions.

The Megger.—This a very compact and convenient instrument, shown in Fig. 441, recently brought out for the testing of the insulation resistance of lines, no batteries being required for the tests. Fig. 442 shows the connections. A commutated magneto-electric generator (shown on right) is used to produce the continuous testing current, and the field-magnets of this also serve as field-magnets for an "ohmmeter" (shown on left). This, like the D'Arsonval galvanometer, is constructed with a pivoted coil, called the "current" coil, moving in the gap between the poles of the field-magnets and an "intensifying" hollow iron cylinder; but, in addition, a "pressure" coil is fixed to the pivot, with its plane at an angle of about 50° to the "current" coil, as shown in the figure. The "pressure" coil is a smaller one, and only embraces one side of the hollow iron cylinder, which

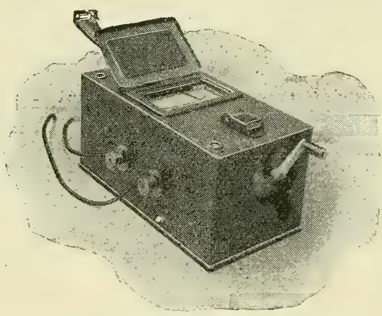


Fig. 441.—"Megger" Insulation Test Instrument

has a gap in it, as shown. A needle attached to the combined coils moves over a graduated scale.

The "current" coil is joined directly in the line circuit, while the "pressure" coil is joined as a shunt. With a high resistance in the line, the latter coil gets nearly all the current, and tends to set in the gap at right angles to the magnetic lines, while with a small line resistance a large current passes through the "current" coil, and this tends to move in the opposite direction to the pressure coil. The actual position

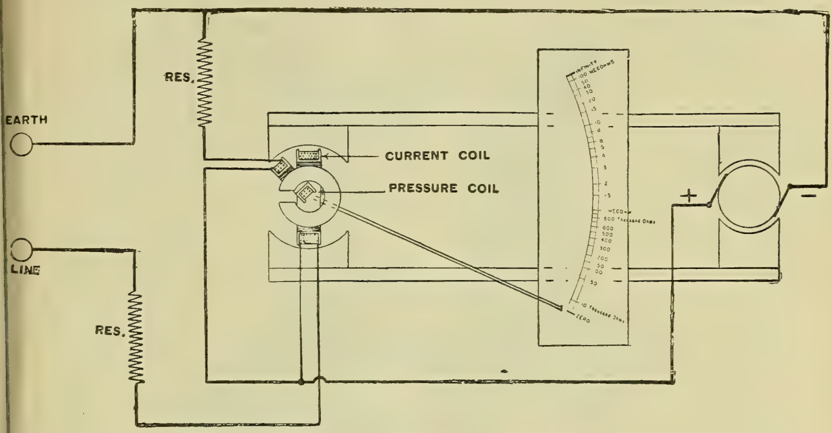


Fig. 442.—Connections of "Megger"

taken by the combination is due to the resultant of the two opposing forces.

In the instrument generally used for telephone work the generator produces a voltage of 500 volts at 100 revolutions per minute, and the scale is graduated from ·01 to 100 megohms. There are also two compensating resistances, connected as shown. The readings of the instrument are independent of the E.M.F. of the generator, but, as in the case of the Wheatstone bridge, the sensibility of the instrument is increased the higher the E.M.F.

Inductance.—Of late years inductance has become of so

much importance that it is necessary to be able to practically measure the actual inductance of apparatus and lines.

For the testing of coils the simplest method is by means of a Wheatstone bridge, and a *variable standard inductance,* such as that of Professors Ayrton and Perry, shown in Fig. 443. This is made up of two equal coils joined in series, one being fixed, and the other pivoted vertically, so that it can be turned at an angle to the other coil. The inductance can be varied

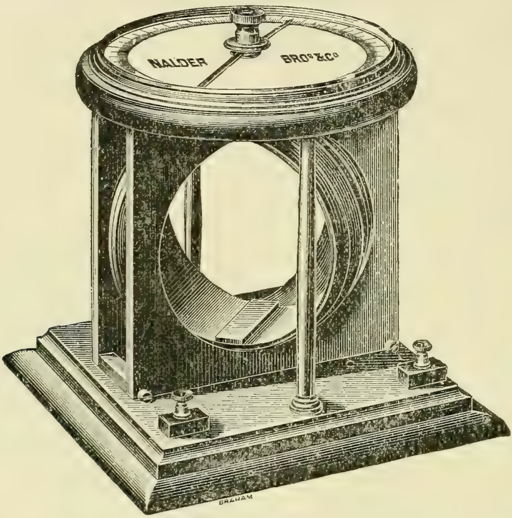


Fig. 443.—Ayrton and Perry's Variable Standard Inductance

between 4 and 40 milli-henrys by turning the inner coil, a pointer and scale at the top showing the amount.

Fig. 444 shows a smaller and cheaper form of instrument for the same purpose, registering between 5 and 25 millihenrys. Both these instruments are made by Messrs Nalder Bros. & Co.

One of these instruments being inserted in the variable arm (between the two terminals at G in the P.O. form) of a Wheatstone bridge and the coil to be measured connected in the ordinary position, a balance is obtained in the ordinary

manner for the ohmic resistance. Then the galvanometer key is kept closed (or is cut out by joining the galvo lead direct to the G terminal of the P.O. form), and the battery is reversed by a reversing key. This causes a kick on the galvo, owing to the inductance of the coil, and the variable coil is adjusted until the kick disappears when the battery is again reversed. Ratios can be used in the ordinary manner.

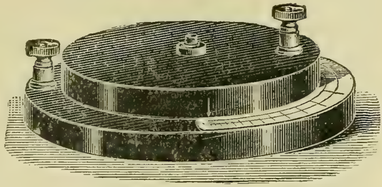


Fig. 444.—Small Form of Variable Inductance Standard

Buzzer and Telephone.—More accurate results may be obtained by connecting a buzzer in the battery circuit, and replacing the galvanometer by a telephone receiver after the ohmic balance has been obtained. The adjustment of the inductance is then made as before, until silence is obtained in the receiver. The buzzer should be kept at a distance from the receiver.

In testing the inductance of lines the capacity introduces a disturbing element, but a near approximation may be obtained by the formula $L = L' \times K R^{2'}$; L, being the measured inductance and L the actual inductance, K the capacity and R the resistance of the line.

If an adjustable inductance is not available a measurement may be made, as shown in Fig. 445, IND. being the coil to be measured. Having balanced for ohmic resistance as before, the kick on the galvo (say d°) is observed when the battery is reversed, the galvo key being kept closed. A small resistance, r, is next added to the IND. arm of the bridge, and the permanent deflection, d', of the galvo is observed when the battery key is closed. It is necessary to use either a Kelvin or what is known as a *ballistic* galvo, in which the time (say T) of the complete swing of the needle is constant. Then the inductance $L = \dfrac{Trd}{4\pi d'}$.

For the formulæ for the calculation of inductance and capacity of lines, see Appendix.

Battery Measurements.—In order to compare batteries or cells, it is necessary to be able to measure currents, electromotive forces, and internal resistances.

Ammeters and Voltmeters.—Instruments for the direct measurement of current strengths are called *ammeters* and those for the direct measurement of P.D.'s or E.M.F.'s are called *voltmeters.* Both these instruments are constructed on several different principles; but the two instruments of any one class are similar in design, and, in fact, one instrument is sometimes made to serve both purposes. The ammeter is

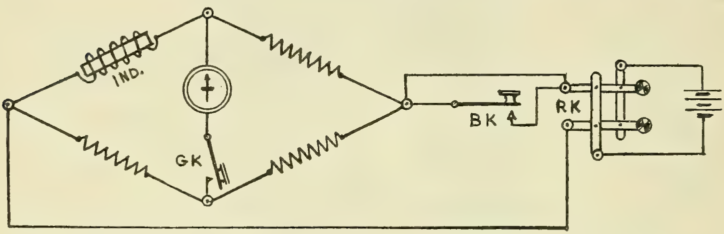


Fig. 445.—Connections of Wheatstone Bridge for Inductance Measurement

usually provided with a thick wire coil of low resistance, which is inserted directly in the circuit to be tested, while the voltmeter has a coil of high resistance, which is connected as a shunt to the circuit to be tested. Both instruments are generally "dead-beat"—that is, their pointers deflect directly to the proper point of the scale instead of vibrating about that point, as is usual with ordinary galvanometers. These instruments should be periodically calibrated (that is, their readings corrected).

E.M.F.—The simplest method of measurement is by means of a voltmeter, this being connected directly to the poles of the battery when the latter is not in use.

Even if a voltmeter is not available, the measurement is comparatively simple. The cell or battery is joined up in

the place of the battery shown in Fig. 432 (the arrangement for taking the constant in insulation testing). The deflection through some known high resistance, say 100,000 ohms, is noted, and then the cell or battery is replaced by a standard cell (such as Clarke's, of mercury and silver, or a standard Daniell), and the deflection again noted. The E.M.F.'s of the two cells will be in direct proportion to the deflections produced in the two cases (of course allowing for shunt), and, knowing the E.M.F. of the standard cell, it is easy to calculate the unknown E. M. F. Thus, suppose the first deflection was 11,000° (allowing for shunt), and the Clarke standard cell gave 10,300°, at the temperature of the test, 19° C., the E.M.F. of the Clarke cell is 1·45 volts; from these the E.M.F. of the cell to be tested,

$$\text{E} = 1{\cdot}45 \times \frac{11{,}000}{10{,}300} = 1{\cdot}55 \text{ volts.}$$

A better method is to charge a condenser with the battery to be tested and the standard cell respectively, noting the discharge deflections in the two cases, as in the capacity constant tests. The E.M.F.'s are again directly proportional to the discharge deflections.

Internal Resistance.—This is a more difficult matter to determine correctly, as the polarisation of the cells varies as the amount of resistance in the circuit when the cell is working, and thus gives rise to variation in the electromotive forces of the cells.

The simplest method is by means of an ammeter and voltmeter, first taking the E.M.F. reading E_1 when the cell is not working, and next the E.M.F., say E_2, and current C, when the battery or cell is joined to a known resistance—a, including resistance of ammeter, which, however, may usually be neglected. Then if r be the resistance required, by Ohm's law $\text{C} = \frac{\text{E}_1}{r+a}$. From this $\text{C}\ (r+a) = \text{E}_1$, or $r = \frac{\text{E}_1}{\text{C}} - a$ (1). Also as the difference of voltage between open and closed circuit $= \text{E}_1 - \text{E}_2$ is due to loss in forcing the current through the internal resistance, r also $= \frac{\text{E}_1 - \text{E}_2}{\text{C}}$. (2). For example, if

$E_1 = 1{\cdot}37$ volts, $E_2 = {\cdot}81$, $C = {\cdot}8$ amperes and $a = 1{\cdot}01$ ohms, then by (1) $r = \frac{1{\cdot}37}{{\cdot}8} - 1{\cdot}01 = 1{\cdot}71 - 1{\cdot}01 = {\cdot}7$ ohm, and by (2) $r = \frac{1{\cdot}37 - {\cdot}81}{{\cdot}8} = \frac{{\cdot}56}{{\cdot}8} = {\cdot}7$ ohm as before.

The above formulæ apply not only to batteries, but to any circuit or part of a circuit.

If direct measurement instruments are not available, the most common method is to connect up the cell by short and thick wires to a reflecting galvanometer, shunted with a piece of wire whose resistance may be neglected. A convenient deflection being obtained by varying the length of wire forming

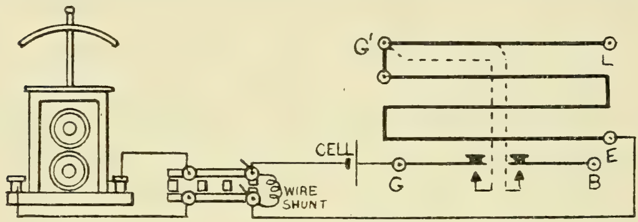


Fig. 446.—Connections of Wheatstone Bridge for Test of Battery Resistance

the shunt, a resistance of, say, 1 ohm is unplugged in a resistance-box included in the circuit, and the reduced deflection observed. Fig. 446 shows the connections using a Post-Office bridge. The deflections in the two cases will be proportional to the strength of the currents producing them, and, therefore, *inversely* proportional to the resistances in circuit in the two cases, which will be r and $r+1$ respectively, if $r =$ the internal resistance of the cell. Suppose the deflections are 160° and 50°, then $r+1 : r = 160 : 50$, or $50r + 50 = 160r$, from which $r = \frac{50}{110} = {\cdot}455$ ohm.

The defect of the above methods is that the E.M.F. may vary during the two tests, the current being stronger in the first case, and the polarisation consequently greater.

Current Strength.—In the absence of an ammeter, the

strength of the current passing through a conductor is determined by finding the *total* resistance in ohms in its path (including battery resistance) and the electromotive force in volts of the battery. Dividing the latter by the former, by

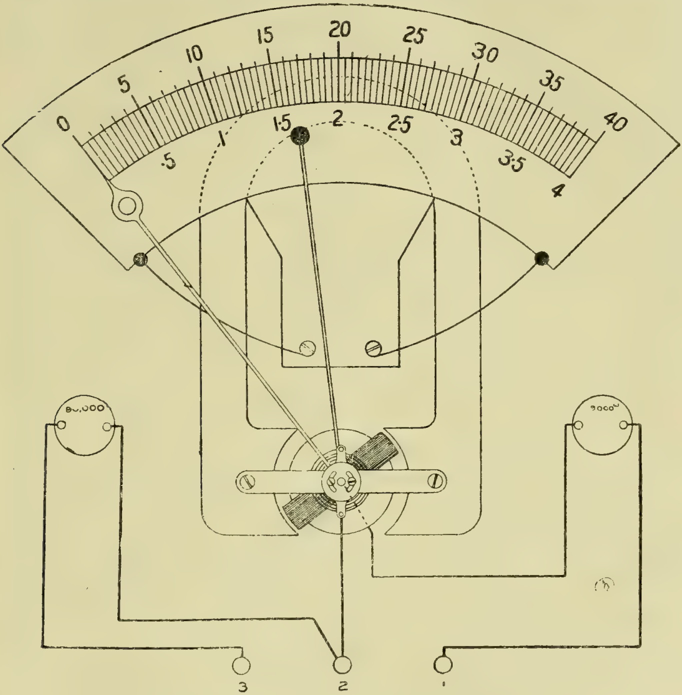


Fig. 447.—Connections of Voltmeter

Ohm's law $\left(C = \frac{E}{R}\right)$ the strength of the current is given in amperes. As currents of much less than 1 ampere in strength are generally used in telephony, it is more usual to measure in *milliamperes*, which is a unit $= \frac{1}{1000}$th of an ampere. The formula then becomes $C = \frac{1000\ E}{R}$. It is important to remember that the *combined resistance* must be taken when

shunts are used, or in any case where the current splits into two or more paths. Rules for finding combined resistances are given in Chapter I.

Testing by Voltmeter.—In the larger exchanges it is now usual to provide a special testing voltmeter, which proves of much value in making rapid, and in most cases sufficiently accurate, tests of the condition of the lines. The instrument used is provided with two scales, one reading from 0 to 40, and the other from 0 to 4. It is constructed on the same principle as the D'Arsonval galvanometer—a coil of wire wound on a non-magnetic metal frame being pivoted between the poles of a strong magnet, and a soft-iron cylinder fixed midway between the poles, as shown in Fig. 447. The movable coil is wound to 1000 ohms, and connections to it are made by two spiral metal hair-springs, the two being so attached as to tend to turn the coil in opposite directions. An aluminium pointer is fixed to the coil, and an adjustable index is also provided, which can be set at any desired point of the scale.

Between terminals 1 and 2 is connected a 9000-ohm resistance coil, which with the working coil of 1000 ohms makes 10,000 ohms. Between terminals 2 and 3 is a coil of 90,000, so that between terminals 1 and 3 there is a resistance of 100,000 ohms in all. Using the terminals 1 and 3, a voltage of 40 gives a deflection of 40 on the upper scale—the current strength being $\frac{40}{100,000} = \cdot 0004$ ampere, or ·4 milliampere. The latter terminals are used when measuring high resistances, such as the insulation resistance of a line, or for tests of capacity.

High Resistances.—With terminal No. 1 connected to an earthed battery of 40 volts, and terminal No. 3 to an outside resistance of, say, 100,000 ohms, the pointer would show 20 volts, or half its former deflection, as the total resistance has been doubled; if to an outside resistance of 200,000 ohms, the deflection would represent one-third, or 13·33, the voltage between the terminals being inversely proportional to the total resistance in circuit.

A table showing the scale of deflections with a battery of

40 volts, and the corresponding external resistances, is given below.

TABLE OF READINGS OF VOLTMETER

Deflection	Megohms	Deflection	Megohms	Deflection	Ohms	Deflection	Ohms
·5	7·900	11	·264	21	90,000	31	29,000
1	3·900	12	·233	22	81,800	32	25,000
2	1·900	13	·208	23	73,900	33	21,200
3	1·333	14	·186	24	66,700	34	17,600
4	·900	15	·167	25	60,000	35	14,300
5	·700	16	·150	26	53,800	36	11,100
6	·567	17	·135	27	48,100	37	8,100
7	·471	18	·122	28	42,900	38	5,300
8	·400	19	·110	29	37,900	39	2,650
9	·344	20	·100	30	33,330	39·5	1,325
10	·300					40	0

It will be noticed that in the second and fourth columns the resistances are given in megohms, while in the sixth and eighth they are given in ohms.

If, as may often happen, the voltage of the battery is not quite 40, then the resistances corresponding to the various deflections will differ from those given in the table, the total resistance, including the voltmeter resistance, being directly in proportion to the total voltage of the battery. With a slide rule the corresponding *total* resistances can easily be obtained by setting the 40 to whatever voltage is shown when the instrument is connected direct to the battery. The following formula will also give the resistances:—$R = V\left(\frac{D}{D_1} - 1\right)$ where R = external resistance; V = voltmeter resistance, including coils; D = deflection through voltmeter and coils alone and D_1 = deflection through voltmeter coils and external resistance. Thus if $D = 38°$, showing that the voltage of the battery is only 38, and $D_1 = 22°$, then $R = 100{,}000 \times \left(\frac{38}{22} - 1\right) = 72{,}700$ ohms.

In making these tests, it is important to observe if there is any earth current present, by connecting the voltmeter to

line without the battery. If present, the deflection obtained should be added or deducted from the deflections obtained with the battery.

Low Resistances.—When resistances of, say, from 2000 to about 50,000 ohms are to be measured, terminals Nos. 1 and 2 should be employed, a 4-volt battery being used. The deflections obtained then correspond to resistances and voltages $\frac{1}{10}$th of those shown in the table.

For still lower resistances, such as the conductivity resistances of lines, etc., a shunt of 1111 ohms $\left(=\frac{10,000}{9}\right)$ should be connected across the terminals 1 and 2. This reduces the sensitiveness of the instrument by 10 when used with a 4-volt battery, so that the deflections then correspond to resistances $\frac{1}{100}$th of those given in the table.

Capacity or Ballistic Tests.—A rough test of the capacity of a line may be made by connecting a reversing key to the earthed battery, so that its connections can be rapidly reversed. The line to be tested is connected to terminal No. 3, care being taken that it is either disconnected at the other end or is connected to a condenser, as in the case of C.B. sub-station instruments. The 40-volt battery being connected to No. 1 terminal, the reversing key is pressed, when a momentary deflection or kick will be given to the needle. This will amount to about 5 divisions per microfarad, so that a deflection of 15 divisions would represent a capacity of about 3 microfarads. This refers to capacities to earth; for capacities from line to line the deflections obtained for a certain capacity are doubled, as both charge and discharge are measured together when the battery connections are reversed.

Fault Clerk's Test Keys.—Fig. 448 shows the arrangements of the key switches (which are of the lever pattern) fitted on the test clerk's desk for the purpose of readily making the desired connections to any line. When a key is depressed, the springs are pressed away from the inner to the outer contacts. The purposes for which the different keys are used are clearly shown in the figure.

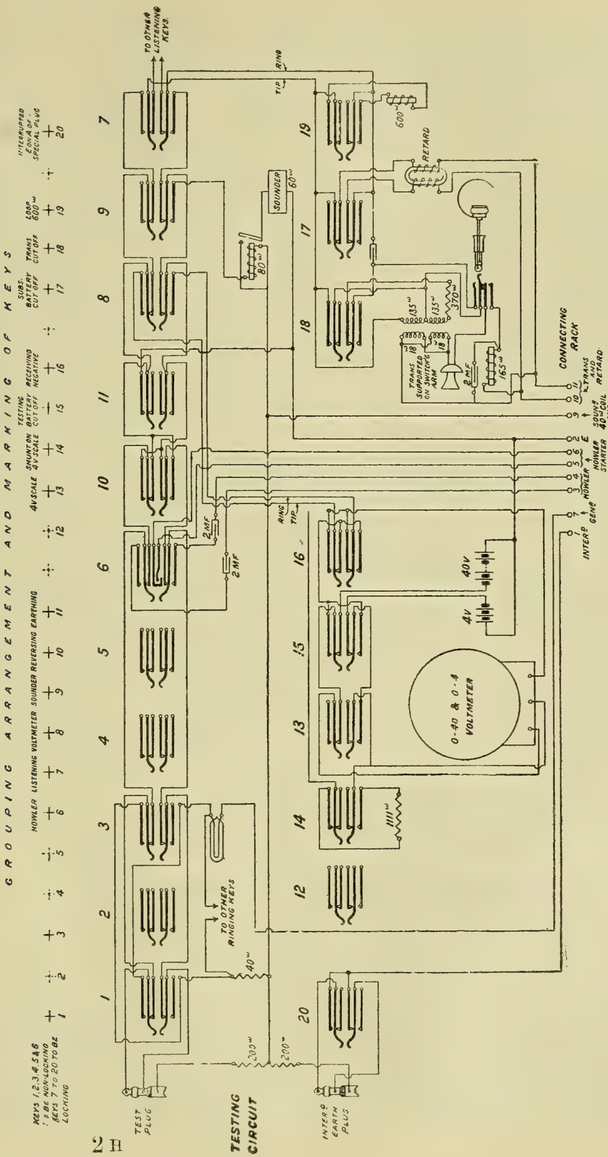


Fig. 448.—Connections of Fault Clerk's Test Keys

Cohen's Galvanometer Set.—This is an instrument designed to measure the very weak telephonic speech currents. The chief part of it is a "barretter" or "bolometer," in the shape of a small electric lamp having a very fine carbon filament (·6 mil in diameter and ½ inch long) and a resistance of about 1300 ohms. When a current is passed through this filament its temperature is raised and its resistance much reduced. It is made to form part of a kind of Wheatstone bridge, being balanced by another barretter. Through both of these barretters a weak steady current from a 2-volt battery is sent, so as to maintain the filaments at a certain critical temperature which gives the best result on the galvanometer.

Fig. 448*a* shows the connections of the instrument, which comprises two barretters B and B_1, a 2-mf. condenser C, two inductances I, a long range potential divider D and a very sensitive moving coil galvanometer with shunt. B is the working barretter and B_1 the balancing one. The alternating speaking current is connected to the bridge through a condenser, and the inductances prevent its passage through the galvanometer, etc. An alternating current of 15 micro-amperes will deflect the galvanometer 5 divisions, and the same strength in direct current will give a deflection of 150 divisions. For measuring alternating current the instrument is set up as shown, the potential divider is then rotated until the galvanometer is at zero, and then the alternating currents connected to the line terminals produce deflections which are proportional to the square of their strengths.

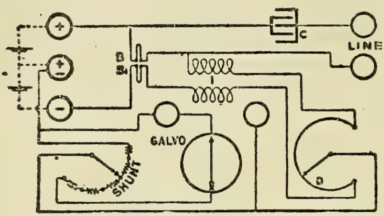


Fig. 448*a*.—Connections of Cohen's Galvanometer Set

Cohen's Barretter Set.—Two somewhat similar instruments as above, connected to the same galvanometer, as shown in Fig. 448*b*, together form a bridge instrument which when operated by an alternating current enables the impedance of instruments, lines, etc., connected at A to be balanced by resistances connected to B_1, or *vice versa.*

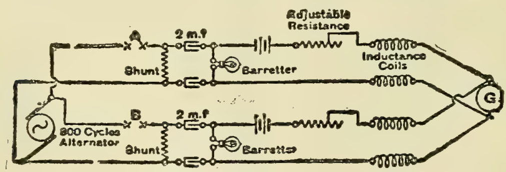


Fig. 448*b*.—Connections of Cohen's Barretter Set

Both these instruments are made by R. W. Paul, of New Southgate, N.

CHAPTER XXX

THE BRITISH INSULATED CO.'S TELEPHONE SYSTEM AND LATER POST OFFICE EXCHANGE PRACTICE

THE British Insulated & Helsby Cable Co. has worked out a very complete central energy system, and has equipped a number of exchanges in this country, the chief ones being trunk exchanges for the British Post Office at London, Liverpool, Manchester, Birmingham, Newcastle, Glasgow and Bradford. It has also fitted up a large ordinary C.B. exchange for the B.P.O. at Cardiff and smaller ones at several other centres.

The system of working is based on the "Stone" C.B. system and whilst the arrangements of the ordinary exchanges follow the same general lines as those of the Western Electric Co.'s the details are worked out diffierently. The subscribers' instrument and line connections are almost identical with those shown in Fig. 242 and do not need again describing, but the cord connections, shown in Fig. 449, it will be seen, differ from those of Fig. 243 in the method of feeding the current to the cords and lines. This is done through four inductance coils R_1, R_2, S_1, and S_2; the two latter forming the working coils for the supervisory relays. The speaking connection through the cords and lines is completed through two condensers joined across each pair of inductance coils as shown, the action of these being as described on page 213. In other respects the connections are similar to those illustrated in Fig. 243, as is also the method of shunting in and out of operation of the supervisory lamps.

Cardiff Exchange System.—The equipment consists of 12 three-position subscribers' sections, each position being fitted for 120 subscribers' lines, which can be increased to 150 if necessary.

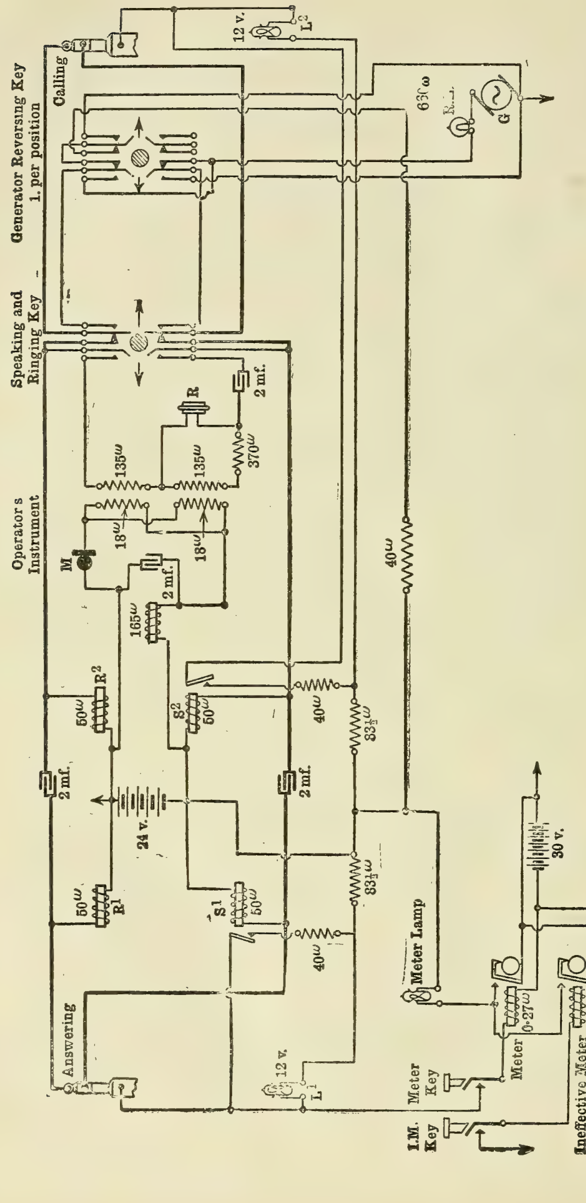


Fig. 449.—Diagram of British Insulated & Helsby Cable Co.'s C.B. Cord Circuit
(By permission of the Proprietors of The Electrician)

The ultimate capacity of the boards is 10,000. The framework of the sections is strongly constructed of angle iron faced and finished off at the front with polished mahogany. The cable shelves are of sheet iron, the one for the multiple cables completely dividing the section and board into upper and lower fireproof compartments when the sheet-iron shutters are in position.

In the lower compartment of each position is fitted the

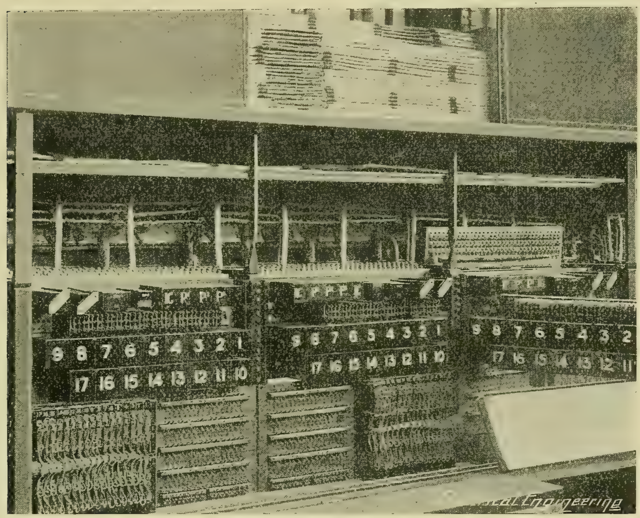


Fig. 450.—Arrangement of Apparatus at Rear of the Sections (*Reproduced from* Electrical Engineering *by permission of the Proprietors*)

apparatus necessary for each operator's equipment, as shown in Fig. 450 (which shows the three positions of a full section). The numbered squares are the backs of the dust-proof covers of the 17 sets of relays and retardation or inductance coils required for the 17 pairs of cords supplied to each position. Above these are the resistance spools and next above these are the condensers, induction coils, relays, etc., required for the operator's instrument and above these is the cord shelf on which

the ends of the cords are fastened, and above these again are the cables connecting to the calling lamps and answering jacks, and also those for the outgoing junction line jacks, which are fitted over the answering jacks. Above these is the dividing multiple cable shelf, on which lie the multiple cables as shown. Below the numbered relay cases may be seen the 17 pairs of cord condensers on the left of the left-hand position and to the right of those are the soldering connectors for joining the various pieces of apparatus together and to the battery leads, and others for joining up the outgoing junction and order wires.

The sections are 6 feet $4\frac{1}{2}$ inches in length, each having 9 multiple panels, but the multiple jacks are repeated every 8 panels and the junction jacks every 6 panels. The multiple jack strips of 20 are $8\frac{1}{4}$ inches long by $\frac{3}{8}$ inch wide, each being numbered 0 to 9 twice, with white dots to identify the No. 5 and No. 15 jacks. Every fifth strip has its lower edge bevelled and painted white to serve as a division for the hundreds.

The incoming junction lines are served by two sections with six operators' positions, each position being arranged for 27 lines. Of the 162 lines thus provided for, 81 are trunk junction lines and 42 are two-way junctions.

Fig. 451 shows the connections of a trunk junction line from the trunk exchange which is situated in the same building. The operator at the trunk exchange on inserting a plug in the jack connects a battery to the bush of the jack. This current splits equally through a 500-ohm coil at the near end and a 500-ohm relay at the junction position at the far end. The energising of this relay causes the 12-volt calling lamp to light, the current also passing through a 40-ohm relay which closes the line contacts to the plug, etc. At the same time current passes through the left-hand contacts of a 350-ohm relay and the bridging 500-ohm inductance coils and through the A and B wires of the junction line and the operators' cord circuit relays to earth, causing a red lamp to show on the trunk position. When the junction plug on the right of Fig. 451 is plugged into a subscriber's jack a double 83-ohm relay is actuated and

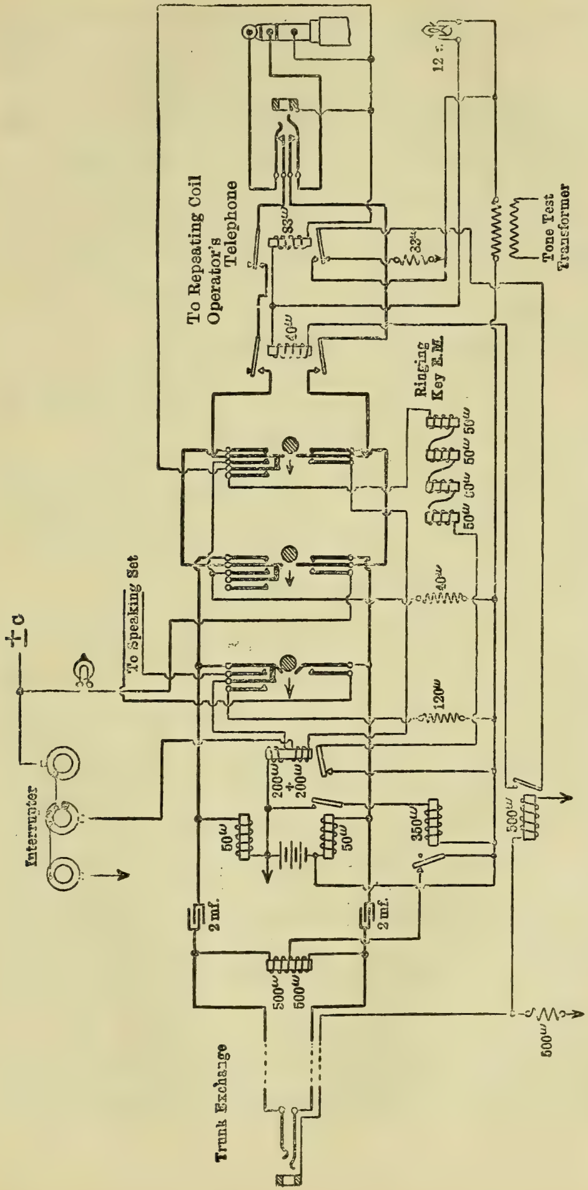


Fig. 451.—Diagram of Junction Circuit Incoming from Trunk Exchange
(*By permission of the Proprietors of* The Electrician)

completes the "A" wire connection and at the same time shunts the 12-volt calling lamp by the 40-ohm relay. When the subscriber replies a 50-ohm supervisory relay is actuated which provides a path for battery through the 350-ohm relay which attracts its armature and cuts off current from the trunk exchange, the red lamp at which ceases to glow, thus showing that the subscriber has replied. Speaking being finished, the red lamp at the trunk exchange is again lit and the operator removes the plug, which by breaking the battery circuit to the 500-ohm relay causes the calling lamp to again light up at the junction position, owing to the cutting out of the 40-ohm relay which was shunting the lamp. A special tone test is put on the sleeves of the trunk junction plugs to inform any other operator making the engaged test that the subscribers' line is connected to a trunk line.

The 5-point jack shown next the plug on the left of the diagram is provided for the insertion of a plug in cases where a subscriber engaged to a local line consents to take a trunk call, and is arranged to send a flashing signal to the "A" position at which the subscriber is connected.

Fig. 452 gives the principal connections of a "two-way" ringing junction circuit from a magneto exchange. These lines are multipled on the "A" sections and also connected on the "B" sections, the latter being their normal connection. If in use on a "B" section as an incoming junction, an engaged test is put on the "A" jacks by a battery connection made through the left-hand contact of the 350-ohm relay and the 1000-ohm resistance spool. The current thus obtained is not strong enough to actuate the 30-ohm double-make and break relay on the left. If the junction is in use on one of the "A" sections the outgoing part of the circuit is completed through the 30-ohm relay, which is actuated by current obtained through the third conductor of the connecting cord and the bush of the "A" jacks; at the same time the apparatus on the "B" positions is cut off. No engaged test is needed on the "B" section on these lines as they are used only as incoming junctions and not as outgoing. The ringing and speaking keys are not

shown in this diagram but they are actually connected on the "B" section as shown in Fig. 451 in connection with the trunk junction lines.

B. I. Co.'s Radial-Arm Transmitter Instruments.—Figs. 453 and 454 show two forms of C.B. wall instruments made by the British Insulated Co. which differ somewhat from the usual British or American types. Fig. 453 shows a complete instrument in a polished wooden case and Fig. 454 one in a metal case. The special feature of each is that the transmitter is

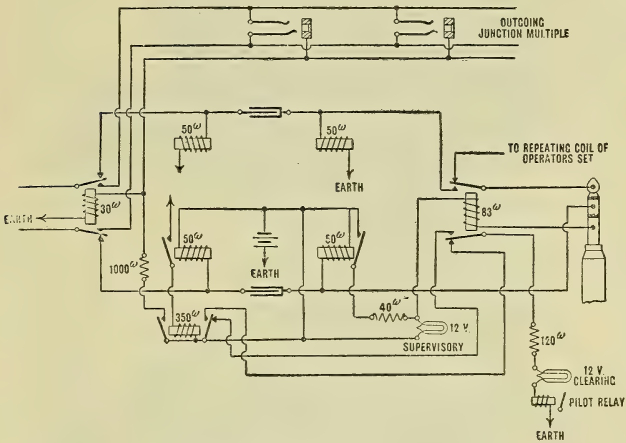


Fig. 452.—Explanatory Diagram of Two-Way Junction Circuit
(*Reproduced from* Electrical Engineering *by permission of the Proprietors*)

fitted on a radial arm which can be swung round so as to accommodate to the different heights of the persons using it.

C.B. Combination Table and Hand-Micro-Telephone Set.—The difficulty which has prevented the use of the generally favourite hand-micro-telephone set in connection with C.B. systems has been that it did not allow of all persons using the instrument to speak close into the mouthpiece owing to the great variation in the lengths of the faces of different individuals between the ear and the mouth. This has been overcome in the instrument shown in Fig. 455 and made by the same firm. In this instru-

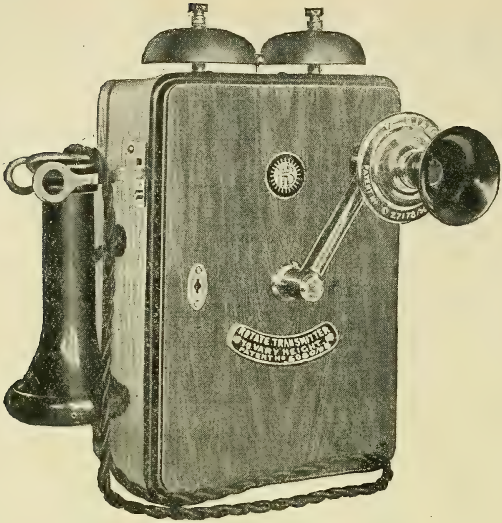


Fig. 453.—Wood Case C.B. Radial-Arm Wall Instrument
(British Insulated & Helsby Cables)

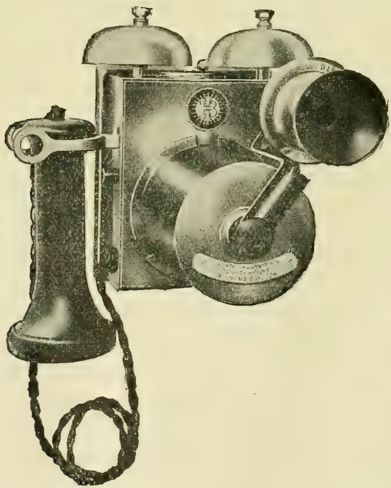


Fig. 454.—Metal Case C.B. Radial-Arm Instrument
(Brtiish Insulated & Helsby Cables)

ment it has been arranged that the transmitter can be slid backward and forward to an extent of about $1\frac{1}{2}$ inches so as to accommodate to the face length of any individual.

Trunk Exchanges.—The trunk exchange at Carter Lane, London, is described in Chapter XIX. Modifications, however, have been made in this exchange and the improvements have

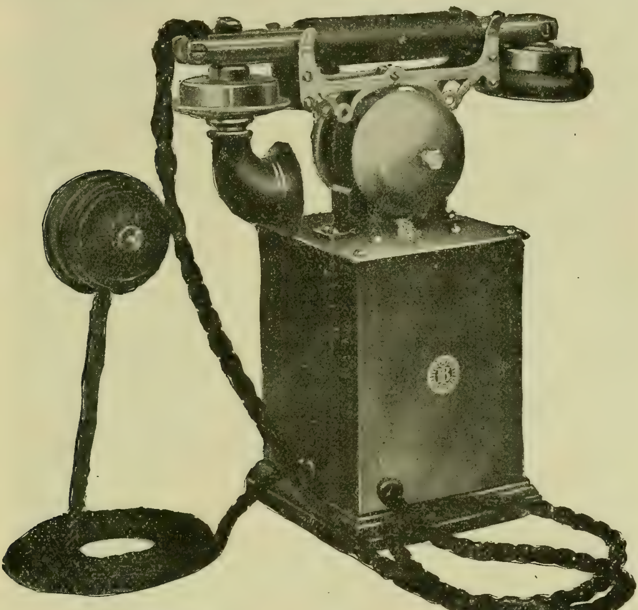


Fig. 455.—Metal Table Instrument. C.B. Adjustable Transmitter
(British Insulated & Helsby Cables)

also been adopted in the provincial trunk exchanges installed by the British Insulated Co. in the various towns already mentioned. The sections of the board are 3-panel ones similar to those shown in Fig. 268, each separated from the next by single panels on which are fitted ticket racks, switches, relay and spare receivers for the trunk-line operators, as shown in Fig. 456, which shows parts of two 3-panel sections divided by

the special panel. In front of the latter is fitted the equipment for a telegraph call wire which will be explained later.

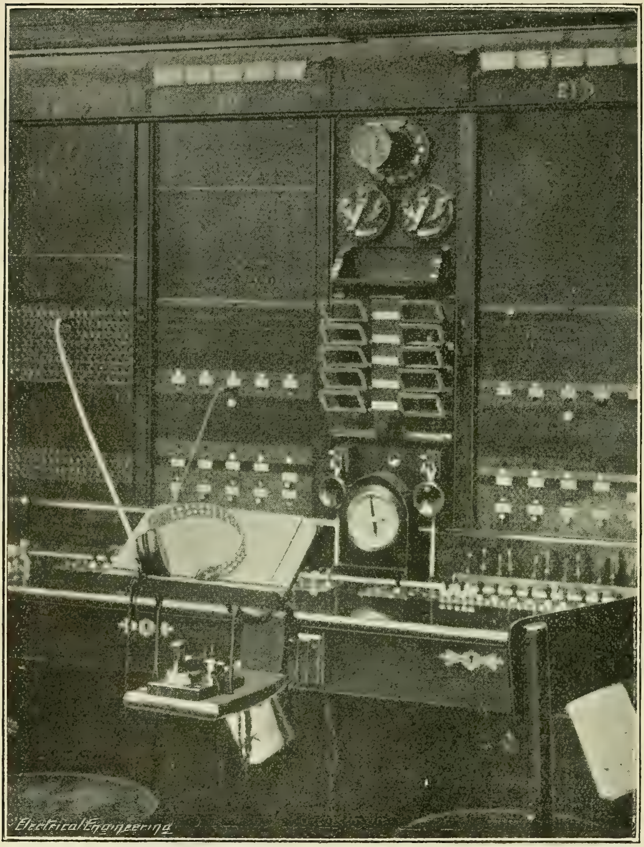


Fig. 456.—A Pair of Trunk Panels, with Intermediate Telegraph Call Arrangement

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The trunk panels are each fitted for 5 trunk lines as usual, the double jacks and lamps for these being fitted in the lower part of the panel with the pilot lamp in the centre above. Over

the latter is a row of 5 jacks and lamps used for transfer junction lines and above these again is a red lamp used for a visual engaged signal. Six pairs of connecting cords and plugs are also provided, each fitted with a combined ringing and speaking key.

Between the trunk panels is the junction panel on which are fitted the multiple junction jacks for different kinds of trunk junctions.

Fig. 457 shows the junction cord side of a pair of trunk cords and Fig. 458 the jack connections of a junction multiple

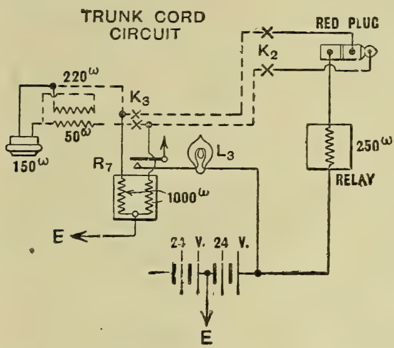

Fig. 457.—Diagram of Trunk Cord Circuit

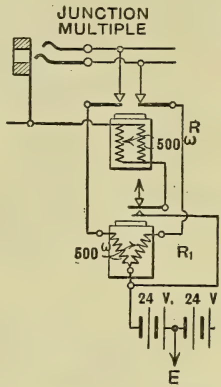

Fig 459.—Junction Multiple

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line which is normally connected to the battery through a differentially wound relay R_1. The socket of the jack is normally connected through a double-wound cut-off relay R to an earth connection through a contact of the relay R.

Engaged Test.—The engaged test is made in the ordinary way by touching the tip of the red plug to the socket of the junction jack. If engaged on another section a click is obtained from the battery connection to the third conductor of the engaging plug cord through the operator's induction coil. Current also passes through one coil of the earthed relay R_7, the armature of which, when attracted, puts earth on one side

of the red lamp L_3 so that the lamp glows and thus gives a visual engaged signal in addition to the click.

When the red plug of Fig. 457 is inserted in the junction jack a current passes through relay R from the third conductor of the cord and actuates it, cutting off the line connections to battery through relay R_1. When the plug is withdrawn the relay R releases its armature and current is connected to line through relay R, and a relay and lamp is operated at the other end of the junction line.

Transfer Multiple Junctions.—For the purpose of the direct

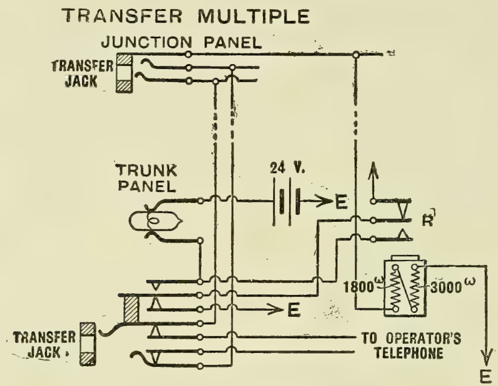


Fig. 458.—Transfer Multiple
(*Reproduced from* Electrical Engineering *by permission of the Proprietors*)

through connection of trunk lines from one to another, each trunk operator or position is provided with two special transfer junction lines, these at the home position being connected directly to the operator's telephone and are multiplied on all the other trunk junction panels. Fig. 459 shows the skeleton connections of one of these lines, the lower part showing the home section and the upper part showing one of the multiple jacks on another section.

A call is made to the home panel by plugging into one of the multiple jacks, when the current from the third conductor passes from the jack socket through relay R at the home section,

and the middle spring is brought to the lower contact, putting earth by the upper jack contact on to the calling lamp, which thereupon glows by current from the earthed battery. The operator can reply directly before inserting the answering plug into the 7-point break jack. When the line is disconnected at the multiple end the relay spring falls back on the earthed spring, which again gives an earthed path for the current through the lamp and the top contact of jack. The engaged test is obtained as with the ordinary trunk junctions.

Telegraph Order-Wire Working.—In front of the ticket panel, as shown in Fig. 456, is fitted a projecting writing desk and underneath this is a table on which is fitted a Morse telegraph

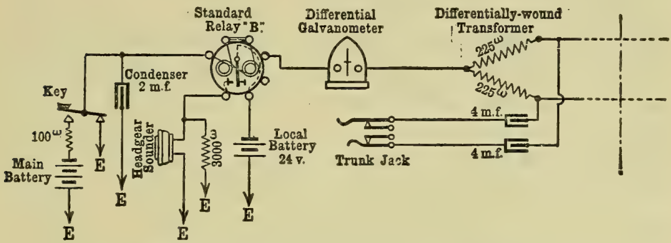


Fig. 460.—Superimposed Call-Wire Telephone Circuit
(*By permission of the Proprietors of* The Electrician)

key. This key with a headgear sounder made in the form of a headgear telephone receiver, as shown resting on the writing desk, is used by a special call-wire operator to transmit and receive by Morse code, and some special abbreviations, the instructions to or from the distant towns, as to the numbers it is desired to connect. These telegraph circuits are "phantom" single earth circuits obtained from the ordinary telephone trunk lines by superimposing, in the manner shown by Fig. 460, which shows the simplified connections of one end of such a line. The connections are so arranged that the operator does not hear in her headgear sounder the messages she herself sends. The inductance of the various electro-magnets and condensers serves to flatten the battery make and

break waves and so prevents interference on the telephone circuits from which they are derived. The transmission efficiency of the latter circuits are found to be only reduced to the extent of the equivalent of about two miles of standard telephone cable by the superimposing apparatus.

These telegraph call wires have been generally adopted where 9 or 10 trunk lines exist between two towns, one of the lines being then fitted for the purpose. The cost of the extra operator at each end is more than compensated by the increased efficiency of the working, an average of 15 trunk calls per hour being put through each trunk line in place of about 10 per hour obtained with the old arrangement without call wire.

Automatic Time Check.—On page 267 the use of the calculagraph for timing the duration of trunk-line conversations is described. This method of timing entails upon the operator the duty of frequently observing the stamped tickets to find out when the three minutes time has expired. To dispense with this observation, an automatic timing device has been introduced which at the end of the three minutes lights up a lamp fitted immediately over the trunk-line jack. On observing the lamp glowing the operator switches in and offers an extension of time, or, if this is not accepted, cuts off the connection.

Fig. 461 gives an outline of the apparatus (which is fitted apart from the switchboard) and shows the connections to the lamp, which also serves as the trunk-line calling lamp. When a call is obtained on the lamp the operator plugs into the jack and makes the desired connection, on completion of which she presses on the "time-check key," which completes a battery circuit through the "time-check coil," the armature of which when actuated lifts and sets the movable riding arm CA, at its extreme position on the ratchet wheel W. This wheel is one of a number (usually 10) of similar ones fitted on a spindle which is driven at a uniform speed by an electro-magnet and ratchet wheel governed by a pendulum clock. The arm CA, which is earthed, is carried round by W for a period of three minutes when its end comes in contact with a hinged plate C

connected to the lamp, which then glows by the current obtained from the 24-volt battery, and this calls the attention of the operator.

If the call is finished the operator restores the arm out of contact with W by again pressing the time-check key, which by means of a curved resetting rod (not shown in fig.) lifts the

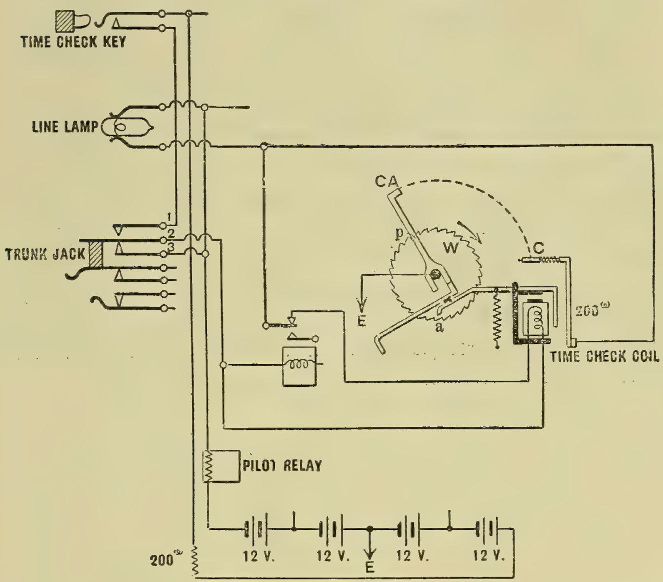


Fig. 461.—Time Check
(Reproduced from Electrical Engineering *by permission of the Proprietors)*

arm CA clear of wheel W. If on the other hand an extension of time is required the operator presses twice on the key, the first restores as above and the second press re-engages for a second period of three minutes. If the connecting plug is withdrawn the riding arm CA is restored to normal, out-of-gear position directly it reaches the hinged plate C by the actuation of the resetting rod by the time-check coil. If the plug is not withdrawn, the arm is withdrawn in about twenty seconds

after the three minutes by the inclined plane of the hinged plate C until it is free from the wheel W, and it is then restored to normal position by a counterpoise weight, not shown.

Trunk Record Circuits.—In the larger exchanges the working of the trunk record circuits is now modified so as to be on the lines of the "transfer" system. Instead of connecting a subscriber directly to the record table operator, as described on page 257, the record line to which he is connected terminates on a jack and call lamp on an intermediate transfer switchboard, on which lines to all the trunk record operators are terminated on plugs with clearing lamps. The operator at this board, seeing the calling lamp glowing, immediately, without speaking, connects the record line to an unoccupied record operator by the plug and causes a lamp to glow on her table. By means of a key-switch the latter operator connects and makes out the record ticket and clears the line by moving over her switch to another position, which then operates a retaining relay and gives the clearing signal to the transfer operator. This method of working results in a much more uniform load on the record operators.

CHAPTER XXXI

SPECIAL EXCHANGE SYSTEMS

In this chapter are given short descriptions of exchanges, or methods of exchange working, which differ from the ordinary magneto or C.B. methods, and for which special advantages are claimed.

Limit of Multiple Working.—By the use of the smallest jacks it is possible to construct an ordinary multiple switch-board which shall accommodate up to 20,000 lines in extreme cases. A board to operate such a large number will, however, be very unwieldy, owing to its large size, and the distances the operators would have to reach in making the connections. If an exchange is required to accommodate more than 20,000 lines some additional arrangement must be adopted. The two chief methods of overcoming the difficulty are the "divided board" system and the "transfer" system. Each of these systems suffers under some disadvantage as compared with the ordinary multiple, and so far they have not been adopted in this country.

Cost of Multiple Switch-Board.—As illustrating the comparatively great cost *per line* of large multiple switch-boards over small ones, Mr C. J. H. Woodbury, in a paper read before "The Insurance Society of New York," stated that in a 10,000 line switch-board there are 2,500,000 soldered connections, or 250 to each telephone; whilst in a 600-line board there are but 43,000 soldered connections, or about 72 to each telephone.

In the larger switch-board there are 10,000 miles of wire, or 1 mile per telephone; while in the smaller board there are 220 miles of wire, or about $\frac{1}{3}$ mile per telephone. The

cost per foot of length may reach $1200 for the large board, and only about half that for the smaller board.

The Divided Board System.—With this, each subscriber is furnished with two or more distinct means of signalling the exchange, the particular one he uses depending on the number of the subscriber he wishes to call.

At the exchange the lines are divided into a corresponding number of sets to form separate boards or sections—lines of numbers up to, say, 20,000 being allotted to an "A" division, those between 20,000 and 40,000 to a "B" division, and so on according to the number of divisions. Each of these sections is provided with a calling annunciator and answering jack for every line in the whole exchange, but only those allotted to a division are multipled on that division. Any subscriber can thus call on any one of the divisions of the board, but is only called up on some one division, depending upon his number. When he wishes to call a subscriber he looks up the number, and then actuates the calling apparatus (generally a press button) so as to give a signal on that special division of the exchange to which the number he wants is allotted.

The divided board system was originated by Mr M. G. Kellogg, who fitted up some large exchanges on this principle in the United States, notably a 3-division exchange at St Louis, with a capacity for 20,000 lines, and a similar one at Cleveland. These boards, however, were not worked on the C.B. system, and in that respect suffered in comparison with later installations. Mr W. Aitken was the first to adapt the divided board to C.B. working, on which subject he read a paper in 1903 before the Institution of Electrical Engineers, London. To that paper the reader is directed for a more detailed description.

St Petersburg Divided Board.—The only example of a C.B. divided board installed in Europe is at St Petersburg. It was fitted by the Western Electric Co., and is a 2-division board arranged for an ultimate capacity of 40,000 lines. Fig. 462 shows the connections of two lines to the exchange and of one pair of the connecting cords.

Each instrument is fitted with two press buttons, one of which when pressed earths the "A" wire, and the other one the "B" wire, of the loop. Each button actuates a calling-lamp relay—the lamp in one case being fitted on the "A" division board and in the other on the "B" division. By an ingenious device, a call on the wrong button may, if discovered before it is answered, be rectified by another call on the right one, that calling relay which is last operated being alone effective.

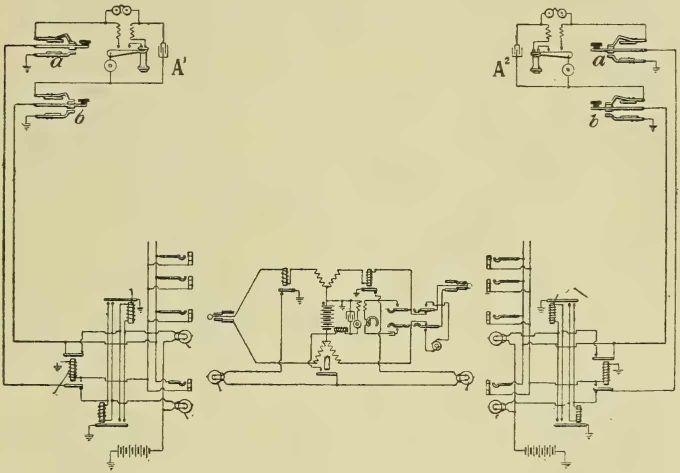


Fig. 462.—Connections of "Divided Board" fitted at St Petersburg

This device minimises a very serious difficulty inherent in this class of board—viz. that any necessity for selection thrown upon subscribers, no matter how simple it may appear, always leads to a great deal of trouble to operators, etc., consequent upon the mistakes made by the subscribers.

The board is otherwise worked as an ordinary C.B. board, the connections of which will be readily comprehended from the diagram.

There is a great saving of multiple-jacks by the "divided" system; for example, the number required for an ordinary

multiple board of 20,000 lines, reckoning 300 lines to each multiple section, would be $\frac{20,000}{300} \times 20,000 = 1,333,300$, whilst with a 2-division board the number required would be $\frac{10,000}{300} \times 10,000 \times 2 = 666,600$. There will thus be a saving of one half the number of multiple-jacks, but there will, however, be twice the number of answering-jacks, calling relays, and lamps required for the divided board. With a 3-division board only a third the number of multiple-jacks would be required, but three times the number of answering-jacks, calling relays and lamps.

The saving in multiple-jacks is also counterbalanced by the extra complication of the apparatus at sub-stations and at the exchange, also by the extra length of cable required for wiring at the exchange, and also by the much longer lines required to run to a single exchange compared with those required for two or more localised exchanges joined by junction lines, which is the more general practice in large cities. Theoretically, the system should be an ideal one in the matter of service, as it enables a very large number to be concentrated in onec entre, and thus dispenses with a large proportion of junction working and its consequent delays.

The Transfer System.—This was originally designed by Messrs Sabin & Hampton of San Francisco, to replace the multiple board, with its great complication and expense, in large centres. It is sometimes called the "Express" system, and is also sometimes called a "divided" board, as the "call" part and the answering, or "order," part of the board are kept distinct from each other. There are many different methods of working, all of them "non-multiple"; in most of them the calling annunciators (usually lamps) and corresponding answering-jacks are fitted at a special board, the "call" or "B" board; while the answering and the giving of instruction for connection is done at the "order" or "A" boards. Short junction lines are run between the two boards, fitted with special apparatus for working automatically and

promptly, as with the junction-line working described in Chapter XVIII. Order wires are also used between the boards, and, in fact, the "transfer" system was the origin of the modern automatic signalling system with lamps, etc., for working both the sub-station instruments and junction lines.

In working, the call is received at the "call" board, and at once transferred by a "B" operator, without answering, through a junction line to the "order" board (a lamp lighting to show the call), the "A" operator at which ascertains the number required, instructs by order-wire a "B" operator at the proper "B" board to connect the required number; the "B" operator selecting the junction line to be used in again transferring the calling subscriber. Supervisory signals are given at the "A" boards, and automatic clearing lamps are lit at the "B" boards when the plugs are removed at the "A" boards, just as in the modern system of junction working.

Three operators are thus concerned in every complete connection, this causing a loss of time, and being a fruitful source of trouble from mistakes in numbers, etc., which more than counterbalance the saving in expense over the multiple system.

In other "transfer" systems the call is answered at the call board, and then transferred by automatically-worked junction lines to the particular call board on which the line of the subscriber wanted is terminated. This is simply following the old plan used before the adoption of the multiple board, except as regards the elaboration of the automatic working of the junction lines.

In a large city like London, where nearly 80 per cent. of the connections are put through junction lines, it might appear that there would be some advantage in using the "transfer" system or some modification of it, as only some 20 per cent. of the connections would suffer a little delay by its adoption. The Post Office have fitted up a second exchange to accommodate some 18,500 lines, in the same building as their "Central" exchange in London, operated on the transfer system—all calls being put through junction lines.

Call-Wire Exchanges.—There were at one time a number of exchanges in this country worked on the "call-wire" principle.

This system of working, introduced into New York in 1878, differs materially from the ordinary systems of exchange working, inasmuch as no annunciators are neccssary at the central offices, the instructions to the operators being given by means of special "call wires" (now more usually called "order wires") altogether distinct from, and in addition to, the subscribers' ordinary lines.

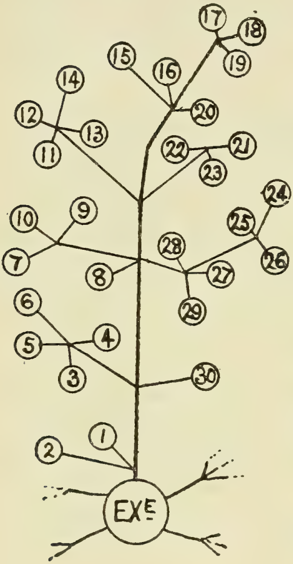


Fig. 463.—Branch Call Wire

A call wire is not confined to one subscriber, but is connected to the instruments in a group of perhaps 40 or 50 (as seen in Fig. 463, which shows a group of 30). A receiver is connected at the exchange end of any one of these call wires, and an operator is continually listening during business hours. A subscriber of the group has merely to press a special key or lever (which changes the connection of his instrument from his ordinary line to the call wire) to place himself in instant communication with the operator, to whom he then gives his own number and that of the subscriber he wishes to speak with. The operator then joins the *ordinary* lines of these two numbers by cords, plugs, and switch-jacks, as on an ordinary board, enabling the subscribers concerned to ring or speak as they wish. When they have finished their conversation they press the call-wire key, and tell the operator to disconnect.

The above would appear to be a very simple and rapid system of working, subscribers being always in touch with the operators. Practical difficulties, mainly due to the inter-

ference of subscribers with each other when speaking on the call wire, and their failure to "call off" when finished speaking, have led to its gradual disuse since the advent of the C.B. system with its automatic working and other advantageous features.

Flat Switch-Board.—A type of switch-board used until recently in some exchanges in this country and in others on the Continent is that known as the "flat" or "table" board, in which the strips of jacks are arranged so that their principal faces form the upper surface of a long flat table. Directly above this table is a "canopy," from which the cords and plug are suspended. Fixed and loose pulleys allow of the plugs and cords being drawn down to the switch-board.

The advantage of this flat form of switch-board is that the operators are enabled to operate from both sides of the table, so that double the number of operators can be employed on any one multiple section, and, therefore, only one half the number of multiple sections will be required as compared with the ordinary upright board. This results in a great saving of cost; but the disadvantages are sufficiently great to more than counterbalance this saving, so that the "flat" board has now become rare. The principal disadvantages are that it is difficult to provide space for signalling apparatus, when such is required; that the continual reaching upward for the cords is a strain on the operators; that dust and dirt are apt to fall through the sockets into the jacks; and that the jacks are difficult to withdraw for the purpose of rectifying faults.

The Post Office Glasgow Exchange System.—This exchange, in which it is intended to concentrate the subscribers to the late Corporation exchanges, is being equipped by the General Electric Co. of London and Manchester. The system of central energy working adopted is that of the Stromberg Carlson Co. of America with some modifications needed to suit special circumstances.

Fig. 464, taken from an article by M. Ramsey in the first number of *The Post Office Engineers' Journal*, shows the general connections of the cord circuit of a subscribers' section. It will be seen that the speaking current from a 40-volt battery

is fed through two coils wound on the same core, so that the C.B. system adopted is that of Stone. The double coil last mentioned with another single winding coil which is connected in the third or sleeve conductor of the connecting cord, together form a compound supervisory relay. The lamps light up when the single coil in the third conductor only is energised and the feeding current has ceased through the double wound coil owing to the subscriber having hung up his receiver. As long as both single and double coils are energised the relay is non-operative. As in the case of the British Insulated Co.'s system at Cardiff and elsewhere, the speaking connection between the connected subscribers is established through condensers.

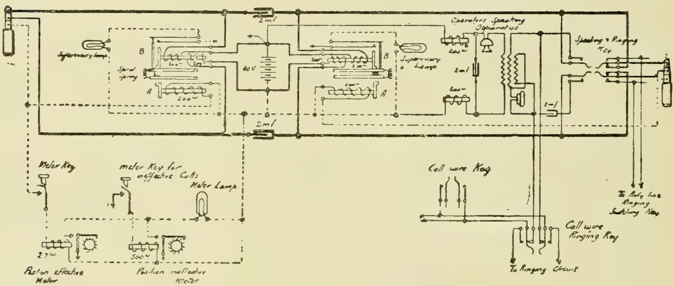


Fig. 464.—Cord Circuit, Glasgow Central Exchange

Most of the other details are on similar lines to those of the Western Electric Co.'s system, as are also the subscribers' instrument and line circuits, so that further description is unnecessary. *

W. E. Co.'s "No. 9" C.B. Switch-Board.—This is a type of switch-board made up in one-position sections and installed in exchanges where the ultimate number of direct subscribers' lines will not for a considerable period exceed 800.

A front view of a section is shown in Fig. 465. It is complete in itself and arranged for a single operator. A board made up of these sections is employed in exchanges where but little junction or trunk work is required. As the rate of calling where such a board is needed is generally small and

* See also a very full account by J. W. Turner in the *Post Office Engineer's Journal* for January 1910.

the operators employed will necessarily be in excess in proportion to the calls—in order that sufficient changes and relief of duty may be provided—the board need not possess

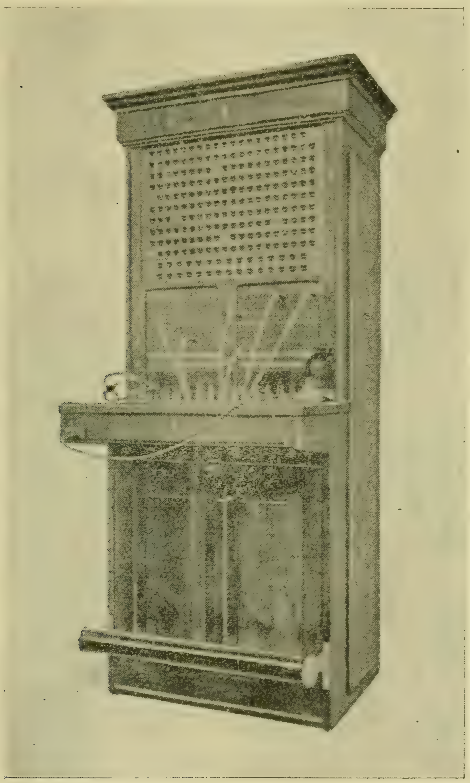


Fig. 465.—Section of No. 9 Switch-Board

the refinements in detail necessary with the larger switchboards.

Line Connections.—Fig. 466 shows the full connections of the board. The jacks are 5-point break ones multipled at

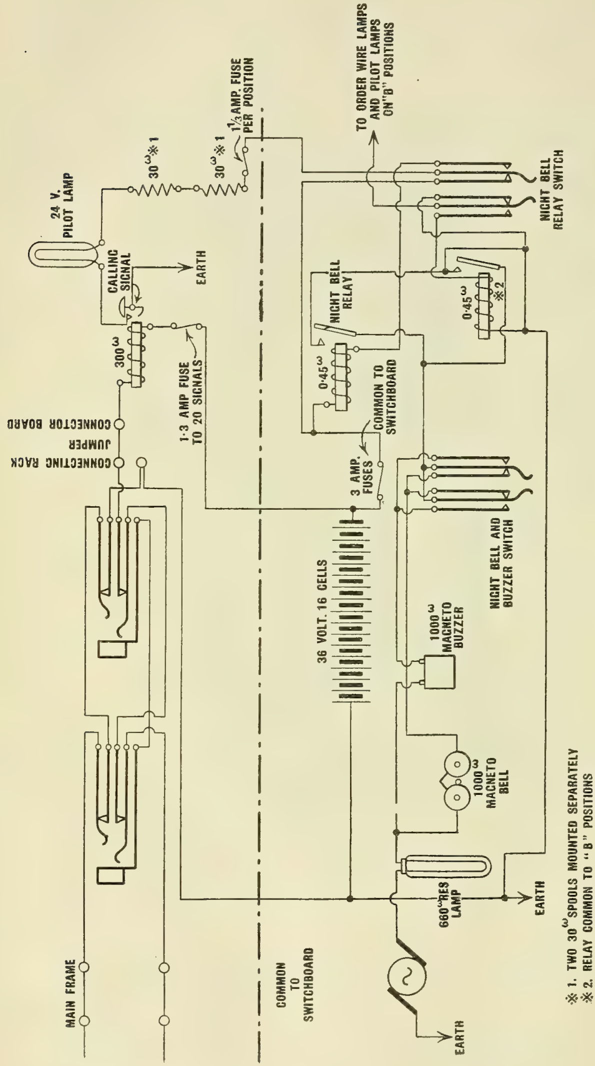


Fig. 466.—Diagram of Subscribers' Line and Night Alarm Circuits
(*Reproduced from* Electrical Engineering *by permission of the Proprietors*)

every fourth section in the lower part of the front and are used for both multiple and answering jacks, no special answering-jacks being installed. The indicators are of the bull's-eye type (see page 148) fitted in the upper part of the sections.

Each section is arranged to accommodate 400 subscribers' multiple-jacks and 80 outgoing junction multiple-jacks all in strips of 20, and the whole board is designed for an ultimate capacity of 800 subscribers and 160 outgoing junction lines. As many as 200 subscribers' lines may be connected to one section, but the number usually fitted is from 140 to 160, the exact number being governed by the traffic records.

The parts shown below the broken line in Fig 467 are common to the whole board.

Cord Circuit.—The cord circuit is shown in Fig. 467. The supervisory coils are differentially wound and act as the impedance coils for the operating batteries in feeding the current to the lines, and the speaking between subscribers takes place through two 2 m.f. condensers which separate the two connecting cords. The working is thus seen to be on the Stone C.B. system instead of on the Hayes system used for the No. 1 type of C.B. boards (see Chap. XVI.).

It will be noticed that in both the cord and line circuit the operating battery is of 16 storage cells having a voltage of 36 instead of as in the ordinary (or No. 1) type of C.B. switchboard where 11 cells, giving 24 volts, are employed. This increased voltage is used in order to keep up the voice transmission to the proper standard, as it has been found that up to about 300^{w} resistance in the line circuit the transmission with the Stone system is not so good as with the Hayes system.*

The No. 9 sections are 6 ft. 3 in. high, 2 ft. 5 in. wide in front, and 2 ft. 9 in. in depth from front to back including keyboard. Up to 15 pairs of cords may be fitted to one section, the corresponding number of pairs of supervisory signals being fitted directly below the calling signals. The former signals are said to be indirect or negative, as they are operated all the time that speaking goes on and restore to normal position when the subscribers replace their receivers, and thus give an indirect signal for clearing.

Fig. 468 gives a general view of the East Ham London

* See M. Ramsey in ***Post Office Electrical Engineers' Journal***, **April 1908**.

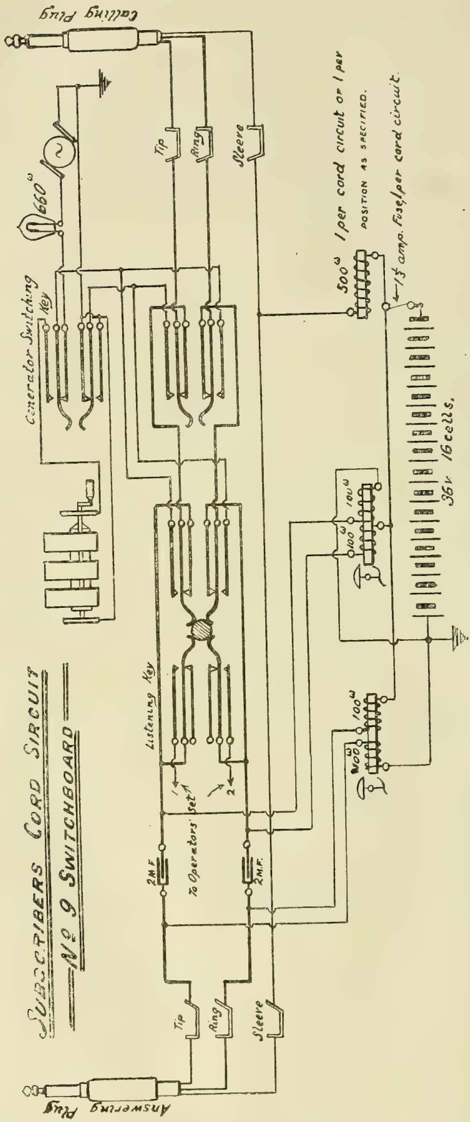


Fig. 457.—Cord Circuit of No. 9 Switch-Board

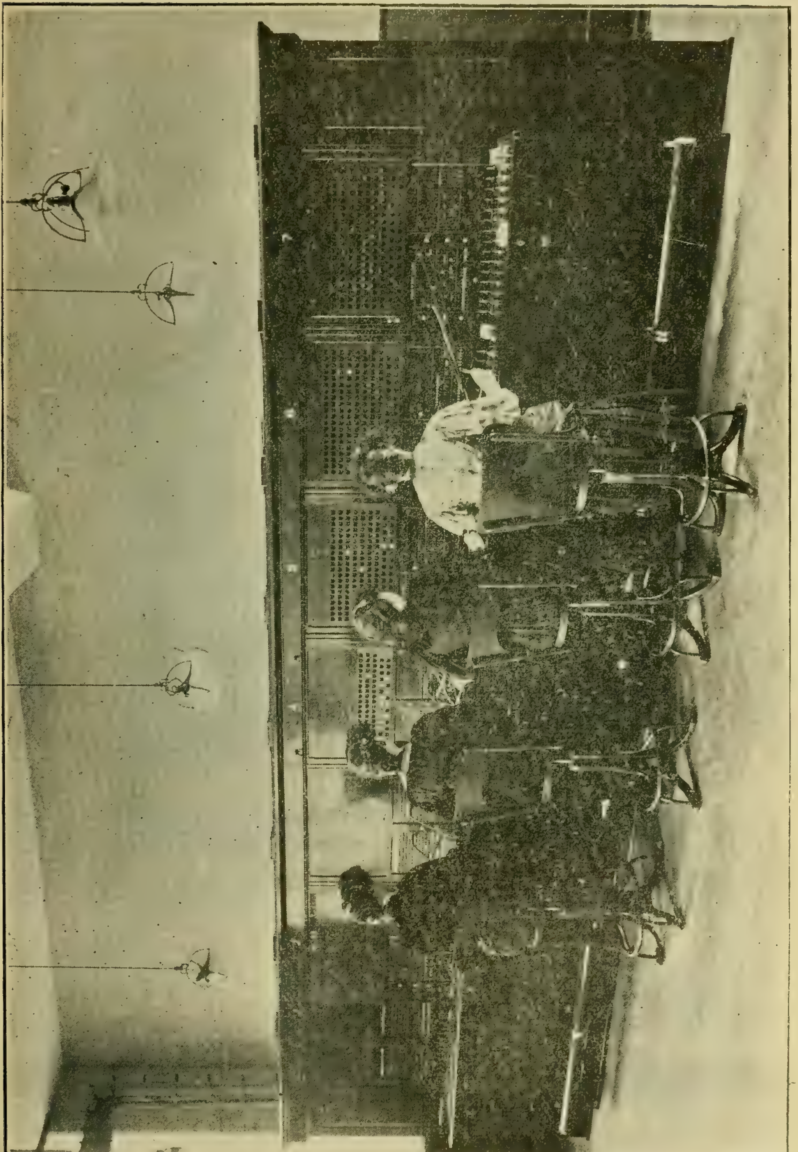


Fig. 468.—General View of Switch-Board
(Reproduced from Electrical Engineering by permission of the Proprietors)

Exchange, where this type of board has been installed. Certain modifications have been necessary, however, to adapt it for

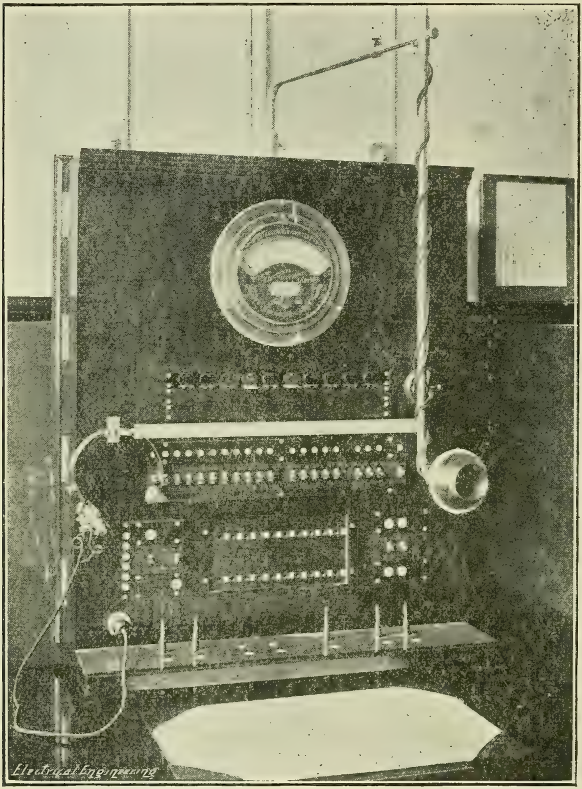


Fig. 469.—Front View of Test Clerk's Panel.
(*Reproduced from* Electrical Engineering *by permission of the Proprietors*)

more extensive junction working than is usually required (see *Electrical Engineering*, 5th March 1808).

Fig. 469 gives a front view of a *test-clerk's panel* used in conjunction with these boards. This panel embodies all the principal features of the test-clerk's desks used in connection

with large C.B. exchanges by means of which the faulty lines, etc., can be tested and the troubles diagnosed and localised.

W. E. Co.'s No. 10 *Switch-Board*.—This is a C.B. board made up in one-position sections similarly to the No. 9 but having all the features of the regular No. 1 or Standard C.B. equipment—that is, lamps are employed for calling and supervisory signals, and the Hayes system of repeating coils for the operator's cord circuits. On this board as much apparatus as possible has been fitted on the section itself, and thus this type of board can be installed in buildings not specially constructed for a telephone exchange, and when the ultimate of 1600 direct lines is reached, or for other reasons a removal is necessary, the board may be taken out with but little expense and loss.

Switch-boards of this type are now installed at Great Yarmouth, Crosby (Liverpool), Rusholme (Manchester), and Greenock.

CHAPTER XXXII

AUTOMATIC EXCHANGES

Within the last few years the automatic method of *switching*, or of making the necessary connections between the lines of different subscribers, as distinguished from automatic "*signalling*," has reached a degree of importance which has been very surprising. It has now become in many cases a serious question for discussion as to which is the better system to adopt—the so-called "manual," or switching by human operators, as at present; or the "automatic" system, in which the switching is accomplished by means of purely mechanical devices.

Although the automatic system has had, and still has, many great difficulties to overcome, it has in America made such astonishing strides that there is little doubt but that it is likely to play a great part in the telephony of the future. In America there are now several large exchanges working on the automatic system; at the time of writing some 23 towns are either working, or are being provided with, automatic exchanges. The largest of these is at Chicago which is already operating upwards of 5000 lines, and is arranged for an ultimate capacity of 100,000 lines.

Not Fool Proof.—What in practice has been found to constitute a very serious defect with the automatic system is that, owing to its secrecy (which in itself is one of its greatest advantages), it is especially open to the silly tricks of the practical joker, who can operate by calling up any subscriber, and give fictitious orders, or use bad language, with but little risk of his being discovered. This has become so serious a trouble in some towns of the United States that special laws have been proposed to frighten the jokers.

Another serious feature is that a "smart" business man, by certain easy operations is able to cause the line of a rival to test engaged at important times, and thus interfere with his business.

On the other hand, there are several important advantages, in addition to secrecy of working, claimed for complete automatic working—such as increased speed, facility for working very large exchanges (even up to as many as 1,000,000 lines, which are out of the limit of a single manual multiple board), and, in the case of large exchanges, economy of first cost and maintenance.

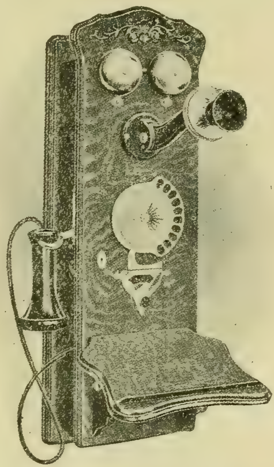


Fig. 470.—Subscribers' Instrument

Strowger System.—So far all installations of automatic exchanges have been on the "Strowger" system. This system has been before the public for many years, but up to recently it had not made much progress. Small private installations have for some time been fitted in this country — one at the Municipal Buildings, Glasgow, and another at St Bartholomew's Hospital, London, but they have attracted but little attention.

Subscribers' Set.—The apparatus supplied to the subscribers consists of the usual transmitter, receiver, ringer, induction coil and local battery, with the addition of "calling" or "selector" apparatus for sending the requisite electrical impulses along the 2-wire lines for operating the mechanism at the central office. Fig. 470 gives a front view of a station wall set, with the selector mechanism fitted below the transmitter arm. The portion of the latter seen on the outside consists of a pivoted dial, provided with a set of 10 finger

holes, numbered upwards from 1 to 10 or 0. This dial is connected to a wheel with 10 teeth to correspond, and a single tooth apart from the others, which serves a special purpose. The connections are shown in Fig. 471, which shows the instrument in the normal condition. Each time any one of the 10 teeth passes a certain spring when moving in a certain direction, the spring makes a momentary earth contact on one of the wires of the line loop, and each time the "odd tooth" passes another spring an earth is put

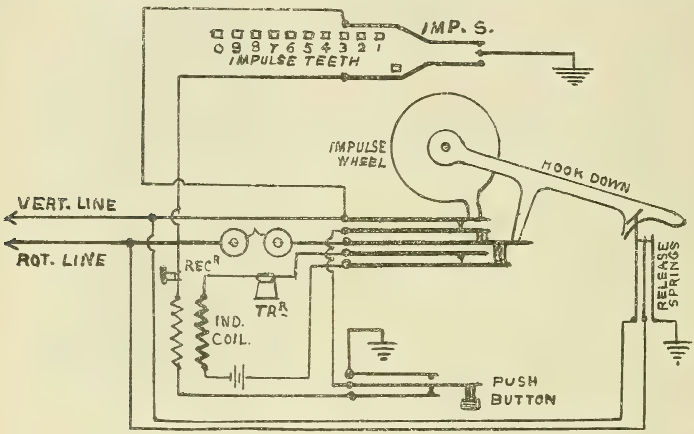


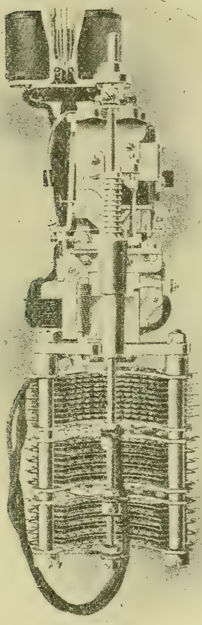
Fig. 471.—Connections of Subscribers' Instrument

on the other wire of the loop. The first wire is called the "vertical" line, and the second the "rotary" line, for reasons which will be presently explained.

Selecting.—To call a number, say 5679, the receiver is first removed from the prong, then a finger is inserted into No. 5 hole of the dial, and the latter is drawn downward, and round, until the finger is stopped by a curved projection at the bottom. The finger is then removed, and a clock mechanism returns the dial steadily back to its normal position, carrying with it the toothed earthing wheel, and causing the "vertical" line to be "earthed" 5 times, and the "rotary"

line to be earthed once, by the "odd tooth." The finger is next inserted in the 6th hole, and again drawn round to the finger stop, and released; next into the 7th hole, and finally into the 9th hole.

By the operation of the mechanism at the exchange, the



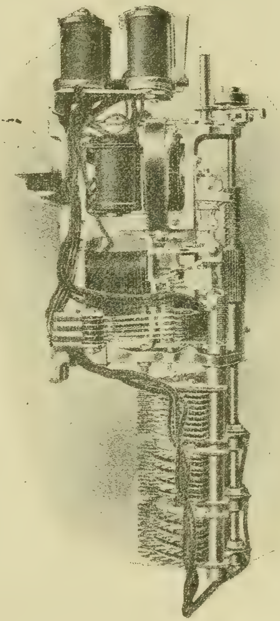


Fig. 472 Front View — Automatic Selector — Fig. 473 Side View

calling line should now be connected to No. 5679 line; but this line may be engaged, in which case a "busy" buzz will be heard on the line. If the line is not engaged the caller presses a ringing button, seen under the dial, which again earths the "vertical" line, energises a ringing relay at the exchange, which sends an alternating current to the ringer of the called line.

Clearing.—When finished speaking, the receivers are hung

on the prong lever, which, in falling to its lower position, causes a simultaneous earth contact on both wires of the loop. This has the effect of restoring all the mechanism involved in the connection at the exchange, to its normal condition.

Connecting Switches.—In addition to his station telephone set, each subscriber has a separate "switch" mechanism provided at the exchange, by means of which the connections required by him are completed. A front view of such a "switch" is shown in Fig. 472, and a side view in Fig. 473. Each is about $13\frac{1}{2}$ inches in height by 4 inches wide and 5 inches deep. At the upper part are fixed 6 relays—2 in the line circuits, and 4 in the local circuits for operating the selective part of the apparatus. At the lower part are 3 sets of what are called "banks" of contacts. These sets *each* consist of 10 rows of 10 contacts, fitted on insulating strips of nearly semicircular shape, the contacts each having a free tongue projecting towards the centre of the curve. The top set of banks are connected to "test" wires, and the two bottom sets to the vertical and rotary lines respectively of the 100 loops.

At the centre or axis of the curves a steel rod is pivoted capable of rotating on its axis, and of moving in a vertical direction. Opposite the lower part of each "bank" a short arm is fitted, on the ends of which are 2 springs, which, when the rod is rotated, sweep over and under the strips of contacts, and are, therefore, called "wipers." On the upper part of the vertical rod a larger cylindrical piece is carried, the upper half of which is turned into 10 circular ratchet teeth, and one side of the lower half is formed into 10 other vertical ratchet teeth. The circular ratchet teeth, combined with what is called a "vertical" electro-magnet and a pawl enable the vertical rod with the wipers to be raised, a tooth at a time, and the lower ratchet, with a rotary magnet and pawl, enable the whole rod and wipers to be rotated on its axis. A double "dog" or pawl prevents either of the ratchets receding until the dog is pulled away by the "release" magnet. These important parts are shown separately in Fig. 474, the lower ratchet being shown cut through, and it and the "rotary"

magnet turned round to show the position of the teeth, etc. The "busy" or "engaged" contact should be noticed at the top of the rod, this being closed directly the rod is lifted. The extension of the rotary magnet armature to form the "rotary finger" should also be noticed.

For a small exchange of not more than 100 subscribers only one class of "switch" is needed, each subscriber having one for his own use, on the "banks" of which all the other subscribers' lines would be multipled.

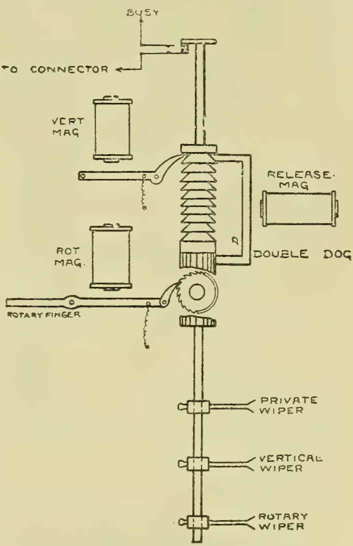


Fig. 474.—Vertical Lift and Release Mechanism

For exchanges up to 1000 subscribers it is necessary to adopt a different system, the lines being then divided into groups of 100, the lines of which are multipled on the banks of about 10 switches, now called "*connectors*," forming, as it were, a distinct switch-board of 10 multiple sections, connected by 10 junction lines to each of the subscriber's own switches (which are now called "*selectors*"), on which their lines terminate. The junction lines are multipled in banks of 10 on each selector, giving 10 sets of 10 junction lines to 10 groups of 100 subscribers. On the "connectors" the junction lines are connected to the mechanism and the wipers, as are the subscribers' lines on the "selectors."

Engaged Tests.—As in these exchanges all the lines are multipled in some way or other, it is necessary to provide an engaged test both for the junctions and for subscriber's lines, and in the case of the former, it must cause the machine to move on until a disengaged junction line is found.

For exchanges of from 1000 to 10,000 lines groups of 1000 lines are formed, each of these groups being made up of 10 subsidiary groups of 100 on 10 connectors, multipled as before. A third machine is now interposed between the caller and the called subscriber. A subscriber's *own* machine, now called a "1st selector," only selects a disengaged junction line to the special 1000 line group to which he wishes to be connected; the "2nd selector" next selects a disengaged junction to the

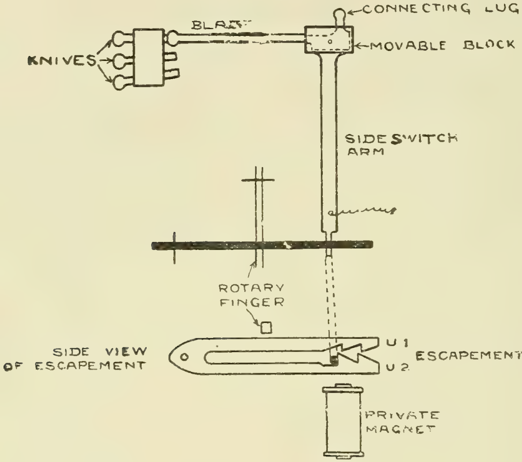


Fig. 475.—Simplified View of "Side Switch" Mechanism

particular 100 group that he requires, and one of the 10 "connectors" completes the connection by joining the wipers of the switch to the particular number required.

For exchanges of more than 10,000 subscribers still another "selector" must be employed to select the particular group of 10,000 to which the line required is connected.

The 1st and 2nd "selectors" are similar machines, but the "connectors" are a little less complicated.

An important movable part in every "selector" and "connector" is the so-called "side-switch." This is a

combination of 4 or 5 switches adapted to be thrown into 3 different positions. It is shown in Fig. 475, which also gives a side view of the escapement at the bottom. It only shows one of the 5 3-point side switches. The end of the side-switch arm projects into a peculiarly-shaped escape-

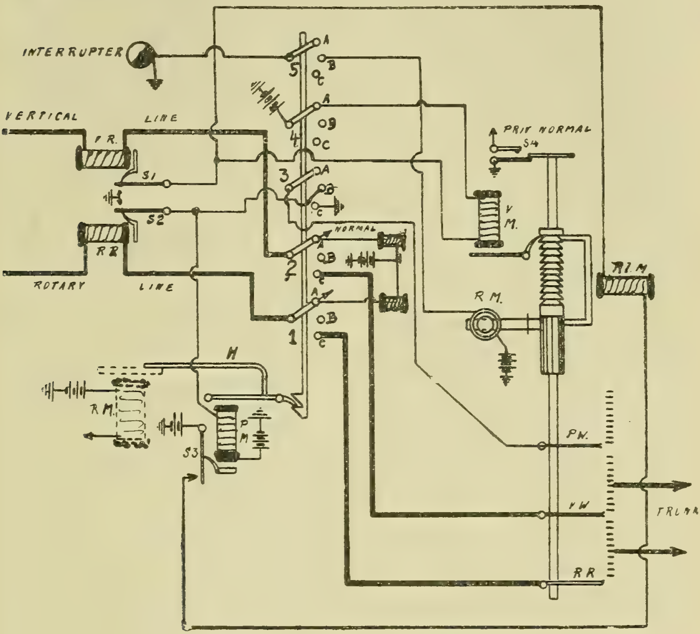


Fig. 476.—Connections of First Selector

ment. When a current is started and stopped through the "private" magnet, the end of the side-switch arm slips under the outer tooth (U 1). As soon as the rotary magnet armature is attracted, the rotary finger (see also Fig. 474) oscillates the escapement, and the side switch is moved to another position. The complete connections of a 1st selector are shown in Fig. 476.

When the "switch" is in its normal position, the side

switch is on the series of A contacts (see the upper section of Fig. 477, which shows the main connections of a line when

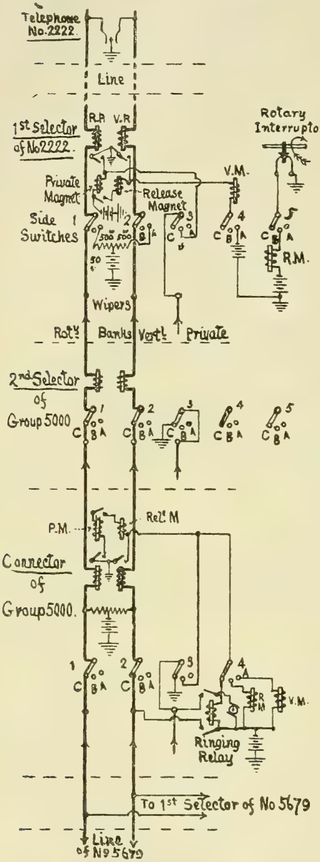


Fig. 477.—Main Line Connections Complete

connected through to another line, such, for example, as when No. 2222 is through to No. 5679). In this position the line relays (V R and R R) are connected through 500-ohm coils to a 50-volt battery. Earthing the "vertical" line actuates the vertical magnet, and earthing the "rotary" line actuates the "rotary" magnet. When both relays are actuated at the same time the release circuit is closed. The object of the impulse through the private magnet (P M) is to cause the switching of the side switch from the "A" position to the "B" position. As soon as this "B" position is attained, the interrupter circuit is closed for the rotary magnet (see Fig. 477). As long as the side switch is in the "B" position the vertical rod is rotated. It will remain in the "B" position as long as the circuit of the private-magnet gets earth through No. 3 switch-test wiper, and an engaged-test contact, as, when engaged, a "test" or "private" wiper contact is connected to earth through a No 3 switch.

In operating the mechanism to call No. 5679, the caller

will first pull No. 5, which will earth the "V" line 5 times, in consequence of which the vertical magnet will be actuated 5 times, and lift the shaft the height of 5 teeth, or to the 5th level. The earthing of the "R" line by the odd tooth at the calling instrument actuates the "R" magnet, and also the side-switch, throwing the latter from the "A" to the "B" position. As long as the side-switch remains in this position the rotary magnet will be operated through the "interrupter," and this will be until a disengaged junction on the 5th level is found by the test wiper, when the escapement will be released by the private-magnet, and the side-switch moved on to the C contacts. Connection will then be made between No. 2222 line and a junction to one of the 2nd selectors at the 5000 group, and the operating mechanism of the 1st selector will be cut out. The operations so far have all resulted from the caller's first "pull" and release of his calling dial.

The calling subscriber's second pull of No. 6 and its release will actuate the relays, magnets, etc., of one of the 2nd selector switches in a similar manner, so as to lift the wipers to the 6th level; then the odd tooth, which always comes in at the end of the return of the dial, actuates the rotary magnet and the side-switch, etc., until a disengaged junction line is found to one of the "connector" switches at the 6th 100 subdivision of the 5th 1000 group. The side-switch of the 2nd selector switch is then moved to the C contacts, and the junction line is connected by another junction line to one of the 10 connector switches of the group, and the mechanism of the 2nd selector switch is cut out.

The caller next pulls and releases No. 7 on the dial. This lifts the wipers of the connector to the 7th level, and moves its side-switch to the B position. The rotary magnet does not now move automatically, but is controlled by the return of the caller's dial from the last pull of No. 9, which will give 9 impulses to the magnet, moving round the wipers of the connector to the 9th set of contacts on the 7th level, and so obtaining connection to No. 5679 line, unless it happens to be already engaged, in which case the release magnet of

the connector will be operated by the earth on the test contact when the wiper reaches it. When the caller then pushes his ringing button, the vertical rod of the connector is raised, and the busy contact is closed at the top of the switch through the "A" contact of No. 2 side-switch, and the caller hears the engaged buzz in his receiver. On the other hand, if line 5679 is disengaged, the side-switch of the connector will be moved on to the "C" contacts, and the two lines will be completely connected. An earth connection will at the same time be put on the test wire of the called number through the "C" contact of No. 3 side-switch.

On pressing the ringing button the caller earths the vertical line, and point C of side-switch No. 4 operates a special ringing relay fixed only on the "connector" switches. This closes the circuit of a ringing motor on the rotary line, through the ringer of No. 5679 instrument, and back to motor by vertical line.

When the conversation is finished the receivers are hung up, and the lever in moving down earths both lines of the loop, and causes the simultaneous actuation of all the 3 vertical relays and all 3 rotary relays, the effect of which is that the double dogs of the 3 release magnets are actuated; the 3 vertical shafts or rods of the selectors and connector are revolved back by spiral springs, and then fall vertically to their normal positions.

The connection of a subscriber's set was given in Fig. 471, the telephone lever being there represented in its normal position with the receiver on the prong. It will be observed that the transmitter is worked with a local battery, and this is one of the drawbacks of this automatic system, as C.B. working was not then feasible.

An even more serious defect is that the speaking circuit of the lines is rendered very poor by the inclusion of several relay magnets and wiper and switch contacts directly in the main lines. This is shown in Fig. 477, which shows the main line connections when subscriber No. 2222 is speaking through to No. 5679, as detailed above. It will be observed that there

are not less than 6 relay magnets and 12 break contacts in the main line circuit, apart from the sub-station connections,

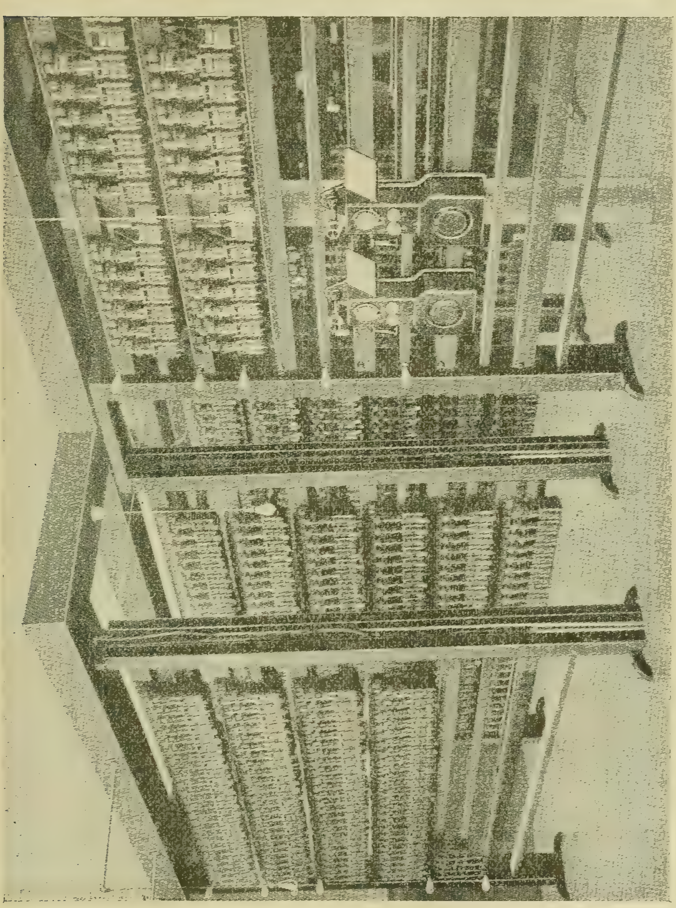


Fig. 478.—View of Automatic Exchange

all of which have to be spoken through. This, of course, is far from constituting an ideal speaking circuit, and must very seriously affect the speaking, especially on a long-distance line.

* See, however, page 520 for later developments.

Equipment.—At the exchange, the automatic switches are mounted on wooden shelves, 25 to a shelf. Six such shelves are generally fixed one over the other in an iron frame, thus providing for 150 machines, as seen in Fig. 478, which shows part of a large automatic exchange. The actual floor space occupied by such a frame is 11 feet 6 inches long by 8 inches wide, but allowing for walking space, etc., 39 square feet is required for the 150 switches, or about 26 square feet per 100 machines.

In an exchange equipped for 1000 subscribers there would be 1000 selector switches and 100 connector switches. In one for 10,000 there would be 10,000 1st selectors, 2660 second selectors, and 1500 connectors.

Power Plant.—As in manual exchanges, the larger automatic exchanges are provided with the usual terminal distributing and arrester frame, with cross-connecting field; but there is no intermediate cross-connecting frame, as this is not needed. Duplicate motor-generators and ringing-motors are provided, and also two storage batteries, each of 26 cells, giving an E.M.F. of about 60 volts. The cells used in the Chicago exchange are of 300-ampere hour capacity.

Faults.—It is stated that in the operation and maintenance of the Chicago exchange one man is required for every 2000 lines, and that the switch and instrument faults average only about 3 per day per 1000 subscribers; but it must be remembered that the exchange is comparatively new, being only brought into operation in 1904. The calls per subscriber per day only average about 2·8, which shows that there is very little traffic as compared with the 10 or 12 calls per subscriber per day of modern C.B. manual exchanges.

Later Developments.—The improvements in the Strowger Automatic System of the last few years have been in the way of central battery working and in the simplification of the circuits and freeing the speaking line from any of the working magnets by arranging that the latter shall be few in number and all connected as shunts to the main speaking line. Many other developments have been made also in the way of party-

line and trunk or long-distance line working in combination with manual exchanges.

In order to show some of the improvements made six dia-

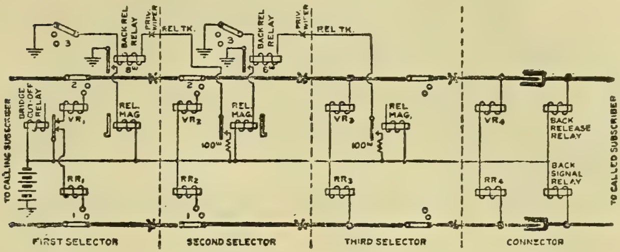


Fig. 479.—Theoretical Diagram of Trunk Release

grams are given which have been taken from one of a long series of articles on the "History of the Automatic Telephone" by A. Bessy Smith and published in *Telephony* of Chicago

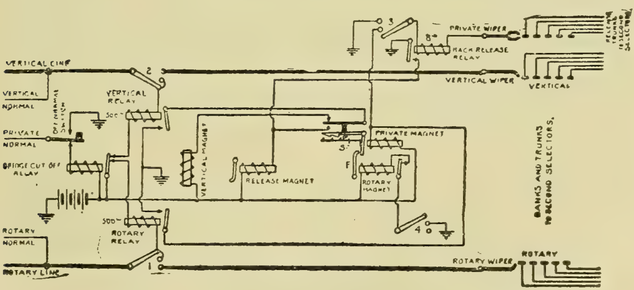


Fig. 480.—First Selector with Trunk Release, Los Angeles

of 13th March 1909. Fig. 479 shows the connections of a complete circuit of the system as installed at Los Angeles. This figure should be compared with Fig. 477 and it will be seen that only two magnets are connected in shunt directly to any one subscriber's circuit, the rest of the release magnets, etc.,

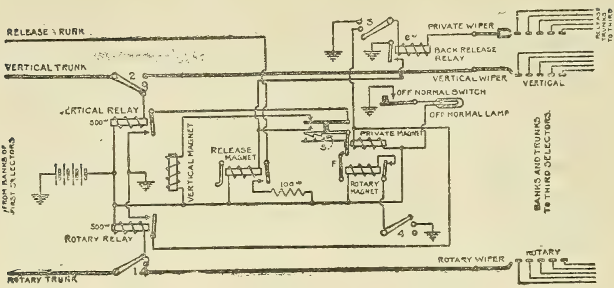


Fig. 481.—Second Selector with Trunk Release, Los Angeles

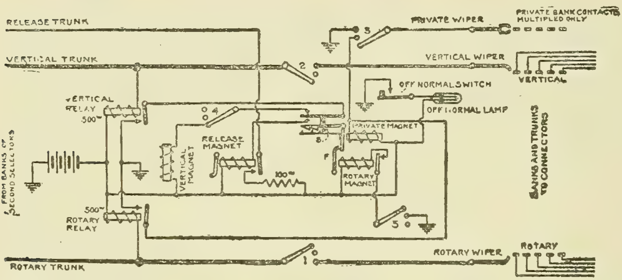


Fig. 482.—Third Selector, South Office, Los Angeles

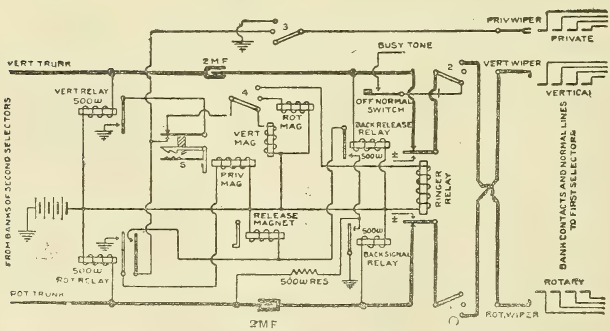


Fig. 483.—Connector, South Office, Los Angeles

being brought into action successively by the aid of the two directly connected ones. Figs. 480, 481, and 482 show details of the connections of the No. 1, 2, and 3 selectors; Fig. 483 of

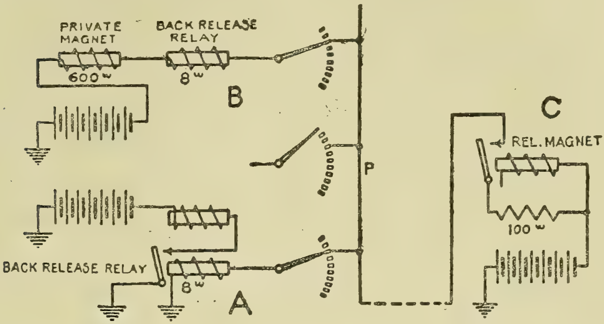


Fig. 484.—Relation of Back Release Relay to Private Magnet

the final connector, and Fig. 484 gives details of the relation between the release relay and the private magnet.

Comparison of these with the ones previously described will show the great improvements that have been made, and these improvements are still being made, common-battery speaking having been introduced into the latest exchanges.

CHAPTER XXXIII

DEVELOPMENT STUDIES OR FUNDAMENTAL PLANS

WITHIN the last few years the method of treatment of the various problems which arise in connection with the provision of the necessary buildings, apparatus, lines, etc., required for the proper telephoning of a town or district, has progressed from a kind of haphazard rule-of-thumb method to a more or less scientific treatment of the problems. These studies have enabled certain standards to be established by which the operating and distributing plant may be compared and computed. The studies are very varied, and as many factors enter into them they become complicated and need very careful consideration.

There are several methods of making such studies, in which the various problems are treated from somewhat different standpoints, but all legitimate methods should lead to about the same conclusions.

The following outline of a method of treatment has been condensed from an exhaustive series of articles by S. D. Levings,* published in *Telephony*, and whilst it applies especially to American towns most of it will be applicable to our own towns, or at any rate will give a very good idea of what is necessary in such studies.

The progressive steps of the studies are given as follows :—

1. Preliminary classification of areas.
2. Population estimate and curve.
3. Methods to be followed in making study.
4. Preliminary work in the office.
5. Field work.
6. Final work in office.
7. Conclusions based on results of study.

* *Telep ony*, Chicago, 20th February to 20th April 1909.

1. *Classification of Area.*—The town in question is classified as coming under division A, B or C, according as the ratio of the use of telephones with a plant ten to fifteen years old has been 10 per cent. or over; 6 to 8 per cent.; or under 6 per cent. of the number of inhabitants respectively.

With new and improved plants it is expected that such ratios will increase in the next twenty years to 15, 12 or 8 per cent. for the three classes of towns. If, however, the detailed studies when carried out show that from some special cause

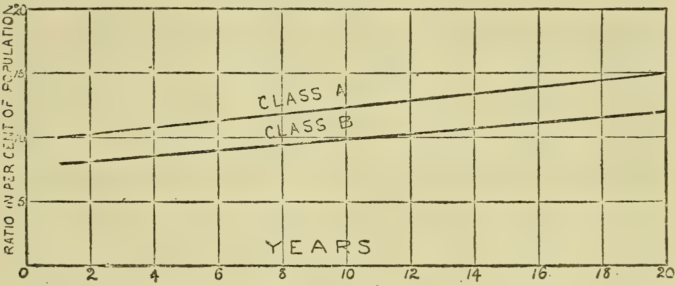


Fig. 485.—Ratio Curve showing future Development of Population

or other such increases in ratio are unlikely to occur in the two higher classes the towns may be reduced in class. A ratio curve is next made out showing the increase in the ratio up to the future twenty years, so that the ratio of increase at any intervening period may be determined. Such curves for A and B classes are shown in Fig. 485.

2. *Population Estimate and Curve.*—The next step is to obtain from Government statistics, local directories and other sources the increase in population of area for a long past period and from these to construct a curve with a projected length showing the population to twenty years hence. Such a curve is shown in Fig. 486. From this may be determined the initial plant to be provided, and from this and the ratio curve the number of telephones expected at five years hence may be computed, upon which will depend the cable plant to be initially laid down.

Any special inequality in the part of the population curve referring to the past should be inquired into and its cause determined, so that allowances may be made for the future if the causes are likely to affect the increase of population in the coming years.

3. *Methods of Study.*—The purpose of this is by actual observation and data obtained on the spot to be able to estimate

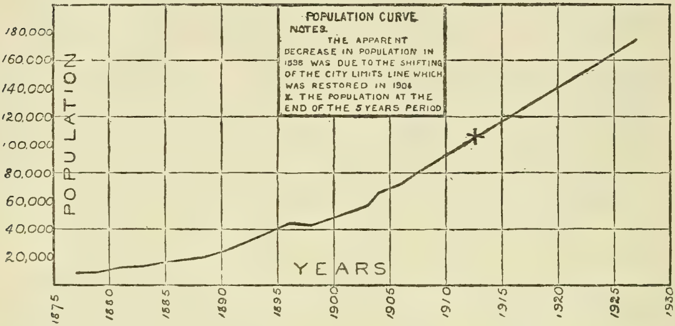


Fig. 486.—Curve showing future Population from Figures of Past and present Population

for the present and the next twenty years the requirements in regard to the following particulars :—

(*a*) The number of telephones required for the initial installation, independent of the figures obtained from the population and ratio estimates.

(*b*) The extent and amount of the initial plant to be constructed.

(*c*) To indicate the number of telephones to be expected at any future period.

(*d*) To show the plant extensions needed at various future periods.

(*e*) To create a basis upon which to calculate the cost of present and future plant.

(*f*) The number of central offices to be built initially and ultimately.

(*g*) The proper location of such exchanges so as to utilise present positions in the future.

(*h*) To provide a basis for classifying service and settling rates to be charged.

The particulars gathered in the actual survey or "house count" will be very numerous and varied and it is therefore very necessary to have a proper system of filing so that the items may be readily available.

Certain assumptions are made as to the rates and classes of service required and as to allowances in proportion of income (which is judged by style of house or method of living) likely to be spent on telephones. The proportion for residential portions determined from many sources in America has been found to be about 2 per cent. of income. This 2 per cent., totalled up, is taken to decide as to whether any or which class of service, such as individual line (taken at say 24 dollars), 2-party line (18 dollars), or 4-party line (at 12 dollars) is likely to be needed.

For business purposes (at say the rate of 36 dollars for direct and 24 dollars for 2-party line) a different basis is taken—viz. that all high-class premises will require at least one direct line, and specially large ones will require a private branch exchange and at least two direct lines. Smaller shops in outskirts will only require 2-party-line service and some not even that. Railway depots, druggists and public buildings are expected to require call offices which may be considered as direct lines at 36 dollars per annum.

It is not expected that in every case those establishments coming under the different headings for service will actually need the service, so that (except for business establishments) a certain reduction allowance has to be made which is that, whilst for a certain class of 2-party-line houses all can be reckoned as needing the service, with a rather lower class only one in two can be relied upon and in the 4-party-line class only one case in six should be reckoned.

4. *Preliminary Work in Office.*—This consists in the preparation of recording books and maps on which to enter the various details obtained by the actual survey.

Maps should be of three scales—(*a*) one of 1 in. to 1000 ft. for general features; (*b*) one of about 1 in. to 600 ft. for details of bridges, street causeways, subways and any special information likely to be of service; and (*c*) a sectional or atlas form of map of about 1 in. to 200 ft. embodying all the essential features. The sections of the latter map should overlap slightly and the divisions should not be made down the centre line of the streets.

The particulars obtained are to be entered in books so arranged that the different pages correspond to different parts or sections of the maps, or for single exchange districts they may be entered on rough copies of the maps made in the books. Suitable maps may be obtained from the corporation or from electric light or gas companies.

5. *Field Work.*—This consists in finding out and judging by actual inspection, and the assumptions as given above, the present and ultimate telephone possibilities of each part of the town.

This matter requires much careful judgment on the part of the men engaged in it, and to ensure that only suitable men are employed on it a test inspection is recommended of a small but rather complicated portion of the area, to be made by all the men independently and the results judged by the engineer in charge from his own inspection. From this test the weak men are weeded out and the different districts assigned to the remainder.

For registering the results of the house-to-house inspection on the maps and books code letters are used as follows:—

Service	Allowance	Code
Individual line residence	Every case	A
Two-party line ,,	,,	B
,, ,, ,,	1 in 2	C
Four-party line ,,	1 in 6	D
Individual line, business	Every case	R
Two-party line ,,	,,	S
,, ,, ,,	1 in 2	T
Private Branch Exchange—1 trunk		X
,, ,, ,,	2 trunks or more	Y
Premises vacant		V

For example, a certain block of land may be registered for present prospects as 5A, 5B, 4C, 4D, 1R and 5V; and the entries may be so made as to show the actual relative position of the buildings in question.

The ultimate number at the end of twenty years is next to be estimated, and requires much careful consideration. It may be assumed that the vacant spaces will be filled up with buildings equal to the majority of those around it and giving rise to subscribers in the same proportion as those in the two highest classes in the neighbourhood. When this has been done the block is said to be "saturated." It should also be assumed that old buildings in a poor state of repair will be replaced by others equal to those of the two highest classes in the neighbourhood. Residential buildings having a number of separate occupants and called "department" houses are similarly dealt with, but the assumptions for futures of vacant property are rather different, the rule being to allow three apartments for each 25 ft. frontage.

In the business district more detail is required as to heights of buildings, number of offices on floors, etc., from which is obtained the number of feet of frontage per office to be used as a constant. For futures and vacant plots 25 per cent. should be added to allow for property of increased value. Allowance must of course be made for the different telephone requirements of different kinds of shops or stores, some requiring much more telephone service than others in proportion to floor area. For private branch exchanges one exchange line should be allowed for every five local service telephones.

6. *Final Work in Office.*—This consists in determining the classification of the town from the survey (which may be found to differ from that shown by the preliminary study), and showing on the maps the routes and number of lines on each route and the grand totals for present and ultimate requirements. The ultimate total is to be compared and checked by the numbers obtained from the population curves and development ratio, and it is upon this comparison that the town classification depends. The development ratio appropriate to the class of

town is applied to the survey figures obtained for the present requirements and the enhanced ratio is applied to the same figures for the twentieth year's requirements. It will usually be found that this will give for the twentieth year a figure higher than that derived from the survey figures, as allowance needs to be made for increase in the actual covering area of the town.

Constants are given below to determine the number of lines needed in the different classes :

Class Code	Line Allowance	Class Code	Line Allowance
A	1	R	1
B	0·6	S	0·6
C	0·4	T	0·4
D	0·1	X and Y	1 to 5 private lines

The above figures are applied to both present and future possibilities. When fractions occur in the products add 1 line for 0·5 or over, but a minimum of 1 is to be allowed for any block or area which does not even reach 0·5.

The figures thus obtained are entered on the preliminary 1 in. to 600 ft. map, the present figures in black above a fraction line and the ultimate figures in red below the line, the totals of each section being also added.

The "line ratios" are next obtained from the full totals of lines and stations, and is the percentage ratio which the lines bear to the stations.

The town is divided into business and residential districts, boundary lines being drawn on the maps with coloured lines, and the future area to be added to the town for the ultimate should also be shown. The ultimate proportion of business to total development is to be taken as the same as present proportions, and the business area occupied at present is assumed to be to the ultimate business area, as the square root of present full area is to the square root of ultimate full area expressed in square miles.

The figures obtained as above should be checked by comparing with the ratio which the present business possibilities bears

to the ultimate business possibilities, or by ascertaining the density of each district, present and ultimate, by dividing the possibilities by the area in square miles in each case. Discrepancies should be looked into and may be found to be due to some very sparsely occupied district being rated too highly in regard to expansion or to a lack of high buildings in a district giving rise to a similar error.

The lines as thus determined are then distributed on the different routes and blocks in the proportions indicated, but judgment has still to be exercised in determining such proportions.

The ultimate residence area and lines are determined in a similar manner, the number of lines being obtained by subtracting the business from the ultimate lines. In dealing with the area it must be remembered that part of the present residence area will become business area.

In distributing the lines several trial attempts will probably be needed before a satisfactory result will be obtained.

When the final distribution of both ultimate lines has been decided and marked on the preliminary map, they should be transferred to a final map, mounted on linen or canvas. The following items are to be plainly noted on this map :—

1. The classification of the town.
2. Per cent. of initial development.
3. Total initial line figures.
4. Total line figures at the end of the five-year period.
5. Ultimate line figures.
6. Per cent. of ultimate development.
7. Initial number of business lines.
8. Per cent. of initial business development to total development.
9. Business lines at end of five-year period.
10. Per cent. of business development at end of five years.
11. Ultimate number of business lines.
12. Ultimate business development.
13. Initial residence lines.
14. Residence lines at end of five-year period.

15. Ultimate residence lines.
16. Present number of central offices to be constructed.
17. Number of central offices at end of five-year period.
18. Ultimate number of central offices required.

7. *Conclusions.*—A detailed report should be made on the results of the development study, giving in detail all the peculiarities of the town and a full estimate of the future growth and of the assumptions adopted to arrive at the figures and all other special particulars likely to be of service. This will complete the study and it will only remain to fix the number and locations of the central offices to be built initially, at the five-year period and at the ultimate period.

For very fully detailed descriptions of the various computations involved the reader is referred to the original articles given in *Telephony* (Chicago) from 20th February to 20th April 1909.

Following on the above articles in the same periodical is a valuable series of articles on the "Location of Exchange Premises" by the same writer, Mr S. D. Levings.

CHAPTER XXXIV

WIRELESS TELEPHONY

Wireless telephony has lately made a great stride forward owing to the fact that means have been discovered for satisfactory transmission in a manner similar to that adopted in wireless telegraphy—viz. by the aid of electric waves projected to a distance through the air.

Previous to this wireless telephony had been carried on to a very limited extent by two methods, which employed respectively (*a*) reflected light or heat rays and (*b*) leakage rays or currents. In the first (*a*) light or heat rays are projected from one reflector and received by another, such as in the case of Bell's photophone, Tainter's radiophone* and Ruhmer's wireless telephone. In Ruhmer's arrangement the light rays of an arc lamp are caused to vary in intensity by forming part of a microphone circuit, and are then reflected by means of a parabolic reflector on to a similar reflector at a distance, in the focus of which is a prepared selenium cell, this being included in the circuit of an ordinary telephone receiver.

In the second system (*b*) of carrying out wireless telephony, leakage of current (or of lines of force) is utilised between two telephone circuits, each formed by a telephone instrument connected by a long or short line to two separate earth connections set as wide apart as possible. The leakage may take place through the earth, or the lines of force from the aerial lines may spread through the air to parallel circuits some distance away, such as across a river, but unless the lines are long compared to the distance separating them but little practical result can be obtained. Examples of the (*b*) system are the Orling-Armstrong and the Preece & Gavey wireless telephony arrangements.

* See Fig. 44.

Telephoning by means of the (*a*) method is restricted by the conditions that the two stations must be visible one from the other, and that to obtain practical results over lines of a few miles in length it is necessary to employ powerful and expensive apparatus at the stations. With the (*b*) method the force which can be utilised diminishes as the fourth power the distance separating the two circuits, so that it is evident that little use can be made of it for long distances. As a consequence of these difficulties neither of these methods can be said to point towards commercial results.

Radio-Telephony.—Telephonic transmission of a kind has been accomplished by the aid of electro-magnetic waves sent through the air, produced by sparking discharges, as used in the earlier and in most of the present systems of electro-magnetic

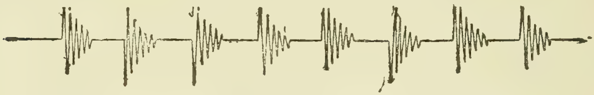


Fig. 487.—Oscillogram of Damped Electric Spark Wires

wave telegraphy. These discharges are obtained usually from condensers, and consist of groups of very rapid alternations of currents having a frequency of hundreds of thousands per second, separated by comparatively long intervals of some $\frac{1}{2000}$th or $\frac{1}{3000}$th part of a second. The discharges in any one group rapidly diminish in intensity and hence give rise to what are called "damped waves." Fig. 487 will give an idea of these discharges.

Such sparking systems of wireless telephony suffered from the defect that the interruptions between successive groups of waves were made at such rapidities that they caused sounds to be produced in the receiving instrument well within the audible range of the human ear. The rate of such sparking was also not uniform, so that the sounds when transmitted were accompanied by other harsh sounds at the receiving end, which interfered greatly with the transmission results.

What was required in order to eradicate these interferences,

which prevented the practical success of such a system as the above, was some method of producing a practically continuous and uniform generation of electro-magnetic waves, the single waves following each other at such a rapidity that if a sound were generated it would be beyond the range of audibility, or above 33,000 alternations per second, which according to Helmholtz is about the limit of human audibility.

Methods for the generation of such continuous high-frequency waves were first discovered by Professor Elihu Thomson, in America, as far back as 1892, but were not utilised for telephonic purposes until 1901, when Professor R. A. Fessenden, of Washington, made improvements in the method of production and attained some success. He, however, obtained much more success with a dynamo which he devised, capable of normally giving 60,000 alternations per second, and could be run as high as 80,000 cycles per second if required.

By the aid of this high-speed alternator, Professor Fessenden worked out wireless telephony to a practical success; so as to give reliable operation over a distance of ten miles.

Professor Fessenden has given a history and details of his work in connection with wireless telephony in articles which appeared in *The Electrical Review* (London), of 15th and 22nd February and 1st March of 1908, to which description I am indebted for many of the particulars here given. See also a paper read before the American Institute of Electrical Engineers in June 1908.

The alternator, which embodies many ingenious mechanical arrangements, is illustrated in Fig. 488. The armature (having a resistance of about 6 ohms) is driven by belt gearing up to a speed of 10,000 revolutions per minute, and the voltage at this speed of 60,000 cycles per second is 60. The operation of the machine is said to be extremely satisfactory, even though running at this high speed for six or seven hours per day. A 1 Kilowatt steam turbine has since been built to drive the alternator, and 80,000 cycles per second are now easily obtained. At 150 volts and 5 amperes of current this is said to be capable of telephoning over 200 miles.

In operation the alternator is generally connected to the "aerial," a high vertical conductor (which, in some cases, is over 400 feet high), through a transformer, as shown in Fig. 489, which shows the connections adopted in one of the forms of transmitting arrangements. In the generator circuit is inserted

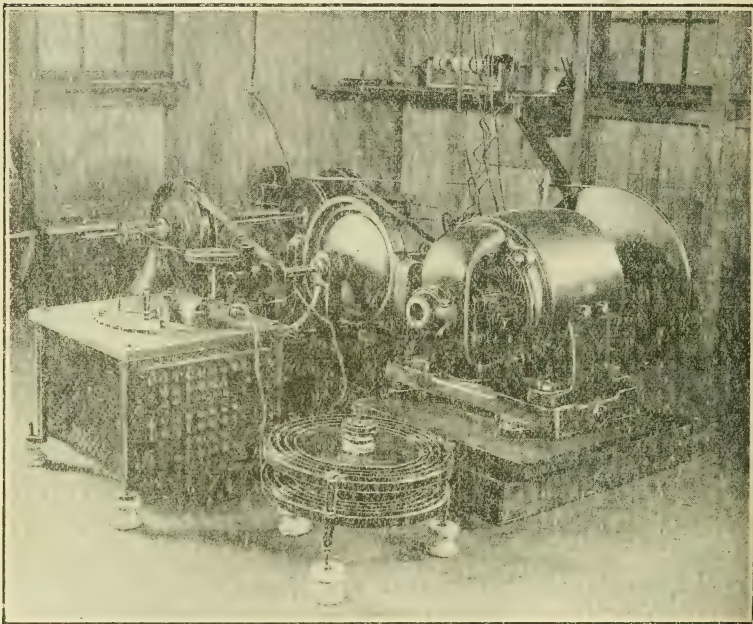


Fig. 488.—Fessenden Alternator for Wireless Telephony

an inductance and the primary of an adjustable variable transformer, which latter has inductive cores. For telephoning over a line of ten miles, in one instance the primary turns of the transformer were ten, and current through them $2\frac{1}{2}$ amperes, voltage 45; secondary coil, number of turns 700, voltage about 3000, frequency 50,000. The number of turns of the transformer are altered to suit various conditions. The aerial is

connected to the secondary of the transformer and the other end of the latter to a carbon transmitter and thence to earth.

The transmitters used are granular carbon ones of the solid-back type, so constructed that they will carry a very heavy current without excessive heating. In one form used the heat generated was dissipated by constructing the carbon chamber with two deep grooves so as to obtain a large air-cooling surface. In a later and more satisfactory form called the "trough" transmitter the same object is attained by circulating water through a "water-jacket" surrounding the carbon chamber. This form is shown in Fig. 490. It is able to carry as much as

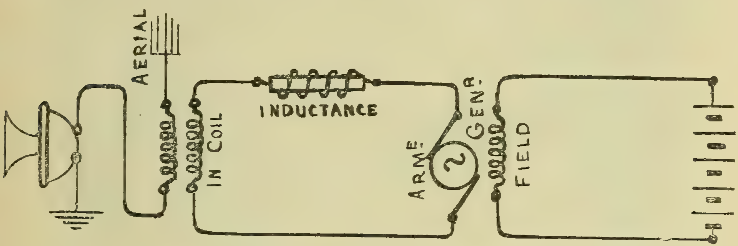


Fig. 489.—Transmitting Station, Fessenden's Wireless Telephony

15 amps. continuously, so that considerable energy (at the rate of ⅛ H.P.) may be transmitted for hours at a time.

The Majorana "Hydraulic" Transmitter.—This is a form of transmitter which has been used with considerable success in connection with wireless telephony. It is based upon the capillary properties of jets of liquid and is made up of a small glass tube from which is spurted a jet of acidulated water under a steady pressure capable of regulation. The glass tube is connected to the diaphragm of the transmitter with an elastic envelope and the jet of water falls between two platinum plates or sheets also capable of adjustment.

With a steady jet there is a constant resistance between the platinum plates, but if the diaphragm is made to vibrate the jet is correspondingly affected and the resistance between the plates is found to vary to a considerable extent and in exact

accordance. As a strong current can be sent through the plates with no liability to heating, it will be seen that we have all the requirements for a powerful form of transmitter with which to vary, in one way or other, the high-frequency alternations sent into the aerial. A distance of 500 kilometres is said to have been wirelessly spoken over with this transmitter.

In operation the aerial is tuned so as to be resonant to the

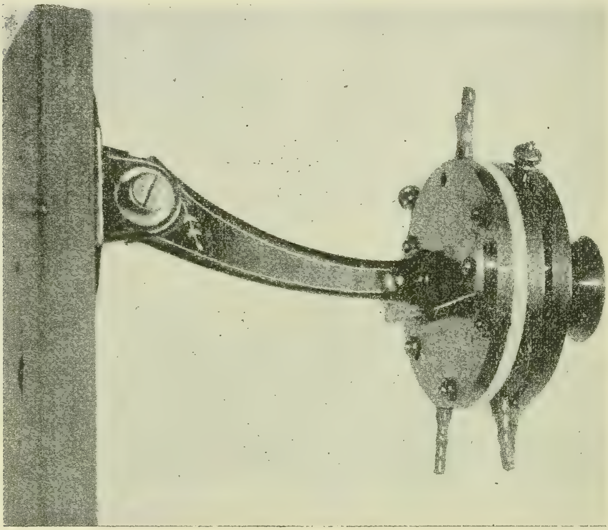


Fig. 490.—Fessenden's Trough Carbon Transmitter

period of the alternator, and acts with regard to the etheric waves in a somewhat analogous manner to that in which a bar of steel fixed at one end and struck at the other gives rise to sound waves in the air, or is even more analogous to the air vibrations in a closed organ pipe. If the vibrations are sufficiently rapid in such a pipe, musical sound waves are sent through the air, the effect being much enhanced if a resonant box or tube is used in connection with the vibrating body ; so

in the case of the aerial conductor, if the electrical vibrations or alternations are sufficiently rapid, electro-magnetic waves are sent through space from the aerial at the speed of light, or 186,000 miles per second.

By speaking into the transmitter while the alternator is in operation, the resistance is caused to vary, the voltage of the surging impulses in the aerial is by this varied in accordance with the sound waves and the etheric waves thrown off are correspondingly influenced.

The transmitter may be connected in the exciter circuit of the alternator, so that it will vary the strength of the exciting magnets and so give rise to variations of potential in the generated alternations, and to similar variations in the aerial surgings.

In another arrangement the transmitter is connected directly in series between the aerial and the generator, the other pole of the latter being earthed, all the parts being thus in one series circuit.

A type of transmitter which has given excellent results is the "condenser" transmitter, which is the old form of Dolbear's telephone, in which the approach and recession of a conducting diaphragm to and from a fixed conducting plate varies the capacity, and affects the potential difference of a conductor in connection with one of the plates and a source of electro-motive force, and thus may be made to affect the resonance of the aerial. It is stated that in one experiment with this transmitter, having a diaphragm two inches in diameter an inward movement of the diaphragm of only $\frac{1}{100}$th of an inch reduced the current from 3·1 to 2·5 amperes.

The discovery of the "singing arc" by Duddell in 1909 opened up a new and promising field for electro-magnetic wave transmisson especially for telephonic purposes. He found that under certain circumstances the electric arc could be set into a state of continuous and very rapid vibration, the frequency depending on the proportion of inductance and capacity inserted in a branch or shunt circuit to the arc. In this branch circuit corresponding wave alternations were produced. It

was found that if the ohmic resistance of the shunt circuit was kept the low speed of oscillation was very nearly given by $n = \frac{1}{2\pi\sqrt{LC}}$. The limit of the number of vibrations with Duddell's arrangement of the carbon arc burning in air is about 40,000, and it was not easy to get more than about 10,000. This is not sufficiently rapid to produce any great practical success with etheric wave transmission, so that Poulsen's discovery that much higher frequencies could be obtained by forming the electric arc in hydrogen or hybrocarbon gases under high pressure and with the temperature of one of the poles kept low by circulating water was a very important improvement. These gases were used because of their high heat-conducting power, and to make the cooling effect still greater the arc is formed between the poles of a strong electro-magnet, which causes, by repulsion of the electrified gas, a rapid circulation of the gas round the electrodes. By such means, steady alternations in a shunt circuit about the two poles of an arc (such shunt containing capacity and inductance between certain calculated limits) can be obtained of very high frequency, even a million per second, and the electro-magnetic waves rising from such alternations would appear to offer a very satisfactory line or conductor, as it were, on which the speech wave undulations may be superimposed.

Experiments were made on this principle by Professor Ruhmer between Berlin and Nauen, a distance of some sixteen miles. At the transmitting station twelve arcs in series were used, each having a carbon and copper pole, the latter pole being kept cool by circulation of water inside. The arcs in this case were not enclosed or under pressure. The arcs were operated by current of 4 amperes, at a voltage of 440. The frequency of the oscillations thus obtained being 400,000 per second.

Fig. 491 shows the connections at the sending end, one arc only being shown. The comparatively small variations in the carbon microphone cause very great fluctuations in the arcs and in the shunt circuit, and these, through the medium of the trans-

lator, correspondingly influence the surgings in the aerial and the transmitted electro-magnetic waves.

Poulsen has since then succeeded in transmitting speech between Copenhagen and Berlin, a distance of 290 miles. The transmitter used was a multiple one made up of 12 solid-backs connected in parallel and so arranged that all are operated by one tubular mouthpiece with branches to each of the transmitters.

The Receiver.—In order to utilise the transmitted etherial waves for telephonic purposes, they are gathered up or inter-

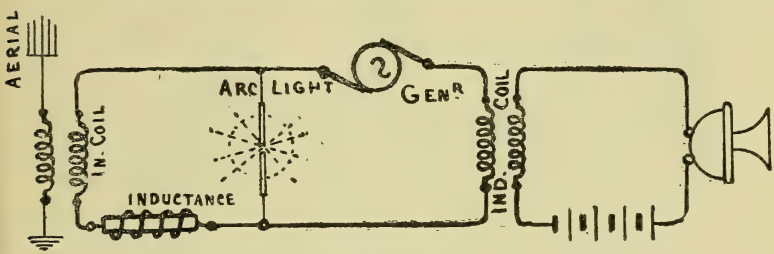


Fig. 491.—Singing Arc Method of Transmission

cepted by another " aerial " at the distant station, and various types of receivers are used in connection with this aerial for converting such received etherial waves into conducted electrical waves or currents, and then into corresponding sound waves.

Liquid Barretter.—A receiver which has been much used by Professor Fessenden is known as the " liquid or electrolytic barretter." This instrument is a small cylinder containing a conducting liquid, such as nitric acid, immersed in which is a metal diaphragm having a very small hole in the centre, opposite which hole is fixed a very finely pointed platinum wire about $\frac{1}{1000}''$ dia. connected to the collecting aerial. The received waves act upon the layer of liquid lying between the fine point and the rim of the small hole in the diaphragm, causing the resistance to vary in proportion to the intensity of the waves.

The barretter is shunted by a circuit containing a battery and an ordinary telephone receiver as shown in Fig. 492. The variations in resistance produced by the varying strengths of the electro-magnetic waves cause a reproduction of the original sound waves in the telephone.

It is claimed that this receiver, having a resistance of

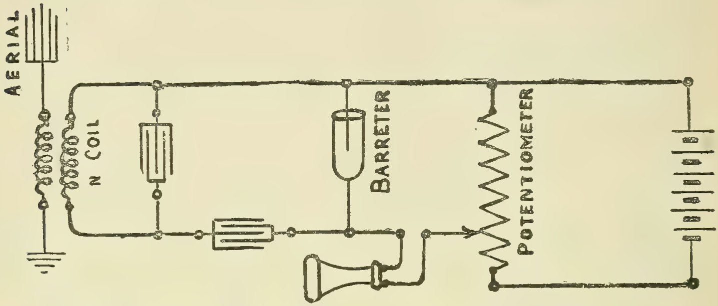


Fig. 492.—Barretter Receiving Circuit, Fessenden's System

2500 ohms, will respond to notes of 5000 vibrations per second, to a high-frequency voltage of 0·00015 volt or to a high-frequency current of 0·00006 milliampere.

Fessenden's Thermal Barretter has also been used as a receiver with good results. This is made up like a small carbon filament electric lamp, but in place of carbon a very short length of platinum wire, drawn down to a diameter of only ·06 of a mil is used. The electric oscillations from the receiving aerial are sent through several of these barretters, which are connected in parallel with a telephone receiver and a source of small electromotive force. Variations of resistance caused by the heating of the fine wire by the received oscillations cause the reproduction of the sounds in the telephone.

Such receivers of electric waves as those just described are "current operated" receivers and act continuously, as con-

trasted with " voltage operated " receivers, such as the carbon or metal filing " coherers " used in wireless telegraphy, which act intermittently by the circuit being first rendered conducting by the impinging of electric waves and then being rendered non-conducting by some mechanical or electrical process.

Fessenden's Heterodyne Receiver.—All forms of the voltage operated receivers are very inefficient. Even the liquid barretter, which is considered by Professor Fessenden to be as sensitive as any in common use, has an efficiency of only about 0·1 per cent. for weak signals. Such a barretter will give an

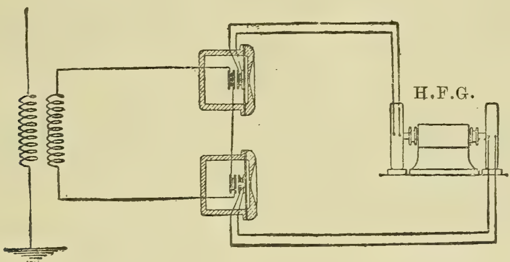


Fig. 493.—Fessenden's Heterodyne Receiver

audible indication with a current energy of between ·01 and ·001 of an erg, while an ordinary telephone receiver will respond to less than ·000001 of an erg (an erg is one ten-millionth of the work done in a second by a current of 1 ampere passing through a resistance of 1 ohm). If therefore any method could be devised for using a telephone receiver to be acted on directly by the received waves, the efficiency would be increased about 1000 times. This has been done by Professor Fessenden by means of his " heterodyne " receiver.

Two of these are shown in Fig 493, connected to a translator and a double high-frequency generator, H.F.G. Each of these has two coils, one cemented to a mica diaphragm and the other furnished with a soft-iron core made up of wires 1 mil in diameter. The latter coil is fixed in close proximity

to the former. One of these coils is connected to a source of high-frequency currents of the same periodicity as used for transmission and the other is connected either directly or inductively to the aerial. The two coils are attracted steadily to each other under normal conditions, but the variations in the received waves cause corresponding variations in the attraction and cause corresponding movements in the mica diaphragms and thus reproduce the sounds.

Fleming's Oscillation Valve.—This is another form of receiving barretter invented by Dr Fleming and is made up of an incandescent electric lamp having preferably a tungsten filament kept incandescent by a separate battery of about 12 storage cells. This lamp is fitted with a copper cylinder which surrounds the filament in the lamp and is made to form one electrode of the receiving circuit, the other being formed by a connection to the filament. This barretter has the property of rectifying the vibratory currents, only those having a positive direction from the copper to the filament being allowed to pass. Such unidirectional currents are said to have a much greater effect on the telephone receiver than the alternating currents.

De Forest's Audion.—This is a receiver based on the same principle as Fleming's Oscillation Valve, but in a double form. Very satisfactory results have been obtained with it. Fig. 494 shows the connections of the audion receiver, and Fig. 495 shows the arrangement employed at the transmitting end.

Crystal Rectifier Receivers.—It has been discovered that certain crystalline substances, such as carburendum, silicon, molybdenite, etc., have the property of rectifying rapid alternating currents and at the same time their resistance varies in accordance with the variations of the received undulations. Being very simple and requiring no auxiliary apparatus in circuit with them, except a telephone receiver, such barretters form excellent receivers for radio-telephony, and seem likely to replace the other forms. As used by Poulsen the crystal is inserted in series with a condenser and telephone receiver in an inductive circuit operated by an inductance coil connected to the aerial.

Transmission.—The received voice reproductions with radio-telephony over long distances are much clearer than in the case of ordinary wire transmission, as no such distortion of the voice

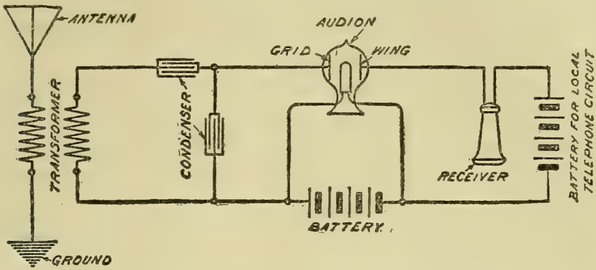


Fig. 494.—Receiving Circuit, De Forest System

waves is experienced even in the longest distances as is met with in wire and especially in cable-wire transmission, so that the received words are very clear even though they may be faint. From this it follows that it is only a case of providing

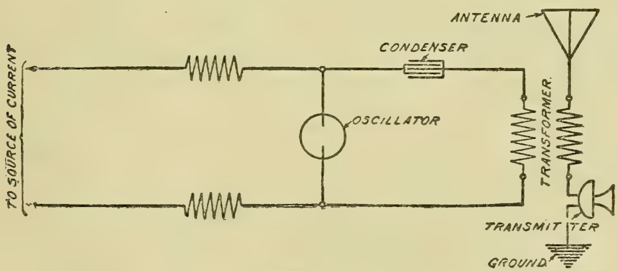


Fig. 495.—Transmitting Circuit, De Forest Wireless Telephone

sufficient power and variation of power in transmission to enable even the longest distances to be surmounted. A single transmitter can only cause variations on a current strength of about half an ampere and even with a multiple transmitter such as used by Poulsen and Fessenden, the total current affected amounts to not more than 10 or 12 amperes. Where carbon

transmitters are used to vary the strength of the field of a high-frequency dynamo the amount of power which can be used is not more than 10 kilowatts, as the self-induction of the armature increases very rapidly with the output; the better method of working being to use the transmitters to vary the amount of magnetic flux in the field magnets.

Radio-telephony has the advantage over radio-telegraphy that a skilled operator is not required. It is not likely that such telephony will supplant the ordinary telephony arrangements for local exchanges, etc., as although it is possible that the difficulty of selectivity may be surmounted the element of simplicity and liability to get out of order will be necessarily less favourable than it is with ordinary C.B. working where the trouble to the subscriber is reduced to a minimum. For long-distance working however there would be a distinct advantage with radio-telephony as there is no trouble from static capacity and the cost entailed should be very much less, the copper conductors used for wire transmission being very costly. For instance it is calculated that when a person speaks on the telephone from London to Glasgow the line of which he has the exclusive use for the time being will have cost some £30,000 for copper alone and on the line between New York and Chicago the cost of a circuit is said to be about £150,000.

Wireless telephony can be used in connection with ordinary wire telephony and speech has actually been transmitted by Fessenden to a wireless sending station and from there automatically relayed to a wireless receiving station and at the latter automatically relayed again from radio to wire telephony and sent over a line and received with perfect distinctness.

The principal use of radio-telephony at present is for communication with ships, the United States navy being already fitted for it by Mr Lee de Forest. It is also extremely useful for communicating with lighthouses and light-ships, especially the latter, where the difficulty of laying a cable line is nearly insuperable, owing to the movements of the ship with the tides, etc.

Atmosphere Absorption.—A difficulty met with in both radio telegraphy and telephony is due to the fact that the energy of the

waves is absorbed by the atmosphere under certain, at present unknown, conditions. This absorption is met with more especially during the daytime, so that most of the work over long distances has to be carried out during the night-time and even then the strength of the received signals is found to vary very much within a short space of time, even to the extent of 1000 to 1. Professor Fessenden has investigated this matter and finds that very high and very low frequencies are most affected and that the frequency least affected is about 80,000 per second.

Comparative Transmission.—Owing to the necessity that speech overtones and harmonies shall be transmitted and that the amplitude of these bear only a small proportion to the amplitude of the fundamental speech tones, the range of distance which can be covered by radio-telephony is much less than that of radio-telegraphy, the latter having a range of about four times the distance with the same power or only requiring from $\frac{1}{5}$th to $\frac{1}{15}$th the power for the same distance according to Fessenden.

CHAPTER XXXV

MISCELLANEOUS APPLICATIONS

The Electrophone.—This is a special application of the telephone for the purpose of supplying connections to theatres, concert halls, etc., so that the performances at such places may be listened to by subscribers in their own premises.

Theatre Arrangements.—Special arrangements are necessary at the theatres for the purpose of connecting the batteries, etc.,

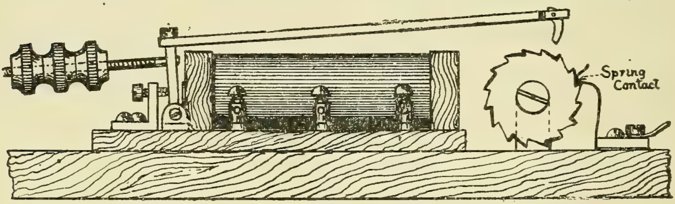


Fig. 496.—Electrophone Combined Induction Coil and Connecting Switch. Scale ½

to the transmitters, as the latter have not been found to work so well by means of a battery stationed at the exchange, and it would be very inconvenient to have to send someone to the theatres when it was desired to connect. This connecting up of the local battery (of about six cells) is done by means of the instrument shown in Fig. 496. It consists of an induction coil fitted with a pivoted armature, to which an arm with ratchet-tooth lever is attached. The ratchet wheel, against the rim of which the spring presses, is so constructed that every alternate tooth is an insulating one.

When it is desired to connect up, a momentary strong current is sent through the line and through the secondary coil, this magnetises the core, attracts the armature and the

ratchet moves the wheel one tooth round, so that the spring makes a conducting contact which completes the primary circuit in which is local battery and transmitter.

When it is desired to disconnect, a strong current is again sent through the line (taking care that it is in such a direction as to assist the magnetism due to the local battery); this again attracts the armature, and moves the ratchet wheel another tooth, so that the spring bears on an insulating part of the rim, and breaks the primary circuit.

This switch must not be too sensitive, or the armature and ratchet would be kept down by the local battery current through the primary coil.

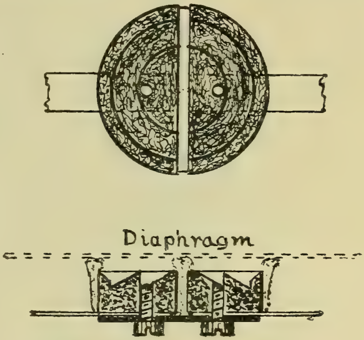


Fig. 497.—Carbon Blocks of Electrophone Transmitter. Scale ½

The transmitter which has been found to give the greatest satisfaction is of the granular type, the back carbon block of which has been cut in two, so as to form two blocks of the shape shown in Fig 497. These form the two electrodes, separated from each other by a strip of felt, a ring of which also surrounds the two. The felt projects above the surface of the blocks, and the spaces formed between the blocks and a thin carbon diaphragm are about three-quarters filled with carbon granules. The diaphragm (which is insulated from the outer case) thus forms the connection between the granules in the two recesses. One of the blocks is connected to a central stud at the back, against which a screw on the end of a spring contact presses, and the other block is connected to a rim of the outer case and makes contact with two slotted springs, as seen in Fig. 498, which shows how the instrument is mounted on a brass base, supported by a thick layer of felt, cemented to a fibre base. This arrangement protects the transmitter from

vibration, and may be fitted on a bracket at the "wings" or placed on the stage of the theatre. A height of about 3 feet above the stage is found to be best for transmission.

Receivers.—The receivers used are of the Ader type, a pair being mounted on the ends of a spring fork, as shown in Fig. 499, each one being fitted with a swivel joint, so that it can be adjusted to the listener's ear. Each receiver is kept in a

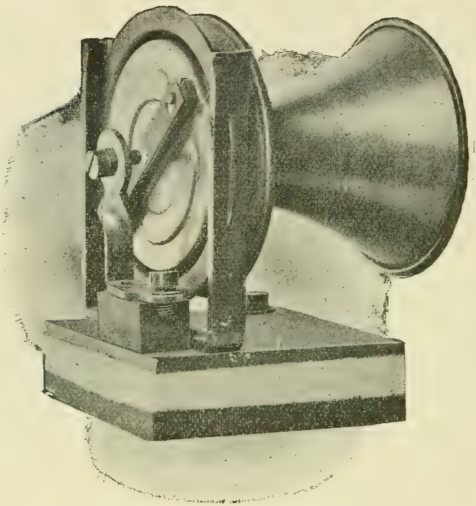


Fig. 498.—Complete Electrophone Transmitter on Weighted Base

separate circuit, so that 4-way cords and jacks are used for connection. Several of such pairs are connected up in two circuits, one receiver of each pair being in each circuit, so that if anything should go wrong with one of the circuits a receiver of each pair would probably be still left working.

The transmission lines terminate in jacks at the central station, and when more than one subscriber is connected through to a transmitter the connections are made through a condenser inserted in each leg of every line connected. This

is done to equalise the volume of sound to long and short lines, and also to prevent an earth fault on any one line affecting the transmission to the other lines connected.

Paris Theatrephone.—The arrangements used in Paris are sufficiently interesting to justify a description.

Ten Ader transmitters, T, *t*, *t*, *t*, *t*, and T′, *t*′, etc., are fixed on the stage, as shown in Fig. 500. Each transmitter is connected by separate line to the central office, and can there be connected to sets of Ader receivers, as shown—a pair of receivers being allotted to each listener, one of the pair being connected to one transmitter, and the other to a separate transmitter fitted on the opposite side of the prompter's box. The figure shows the connection of two such transmitters T, and T′, to sixteen receivers arranged in pairs, ***a b***, ***a b***. A listener using a pair of receivers would thus be connected by the left-hand one *a* to the left-hand transmitter T, and by the *b* receiver to the right-hand transmitter T′. With such an arrangement the transmitted sounds will be most intense from that one of the two transmitters which is nearest the singer on the stage, so that a distinctly different result is obtained from the two receivers of each pair. The effect produced is somewhat analogous to the action of a stereoscope in giving solidity to a double photographic picture. In the case of the telephone it is difficult to imagine that the singer is not close in front of the listener.

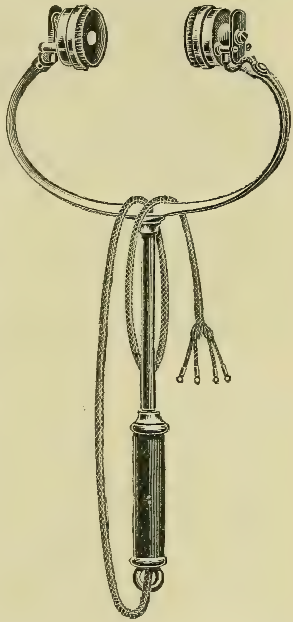


Fig. 499.—Double Receiver for Electrophone

Police and Fire Alarms.—Much use is now being made of

the telephone for the purpose of joining up branch fire and police stations, and also for the purpose of giving alarms of fire, etc., by the general public. For the latter purpose the telephone has the advantage over ordinary electric alarms that particulars of the case can be supplied by the person giving the alarm, so that the needful apparatus may be sent to the exact spot, and valuable time thus saved.

When intended for use by the general public, the telephone

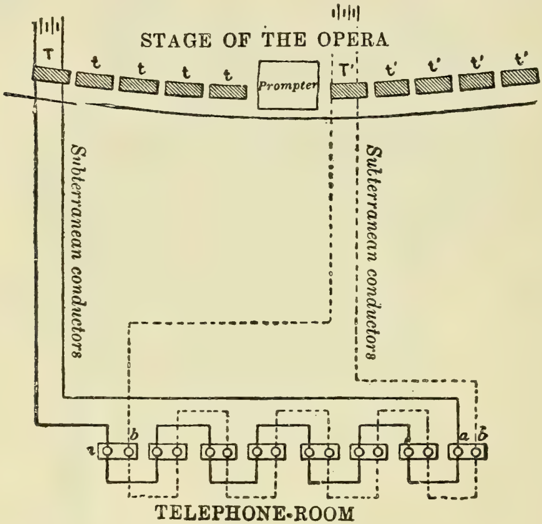


Fig. 500.—Electrophone Arrangements in Paris Theatres

sets are fitted in iron waterproof boxes fitted in the streets, either on posts or on walls, and sometimes so arranged that access can be obtained by privileged persons by key, and by other persons by the breaking of a pane of glass, which allows the door to be opened by pressure of a lever.

The alarm signal can be given to the central station by magneto-generator or automatically by the breaking of the glass, causing the release of a press button; or, again by the lifting of the receiver or hand-microphone from its rest, as in

ordinary common-battery working. The current for the transmitter is also generally supplied from a central battery.

When automatic signalling is adopted it is well, in order to distinguish a signal due to a fault on the line from a true alarm, to include a trembler bell or buzzer in the signalling circuit at the alarm-box. This produces a characteristic sound in a receiver at the central station which is absent when the signal is caused by a line fault.

Motor Car Checks.—Another special use to which the telephone has been extensively put is that of checking the speed and the intercepting of offending motorists. For this purpose lines are run along the main roads in the country districts, and at various points along these lines provision is made for the attachment of portable or permanent telephone sets, so that two or more policemen may keep in touch with one another along any one line, or connected lines, at certain measured distances apart along the road. By means of carefully timed and compared stop watches the speeds of the motors between the points can be easily observed, and the guilty ones brought to book.

Military Applications.—The telephone is used to a very large extent by the military for all kinds of communications in military operations, but more especially for keeping the Commander-in-Chief and the headquarters staff in close touch with every portion and every movement of his army, and for supplying information from the advanced sections as to the movements of the enemy, etc., etc.

The Japanese have made lavish use of the telephone in the war with Russia, and a great deal of their astonishing knowledge of the movements of the Russians has been due to their clever use of the instrument. The telephone has, in fact, become an indispensable adjunct to military warfare on a large scale.

The line wires for use in connecting are usually thin bare copper ones carried on a reel which can be carried on horseback or bicycle, and paid out on to the ground as they move along, another man following, and by means of hooked rods

lifting the wire on to branches of trees, etc., for insulation. (This applies only to temporary lines.) Earth connection has to be made to complete the circuit, and this is done by driving a metal rod into damp ground, or into living trees, so that the sap will make the connection.

The telephone apparatus to be used naturally requires to be simple, light, waterproof, and of substantial construction, so that it may withstand the weather and accidents to which it

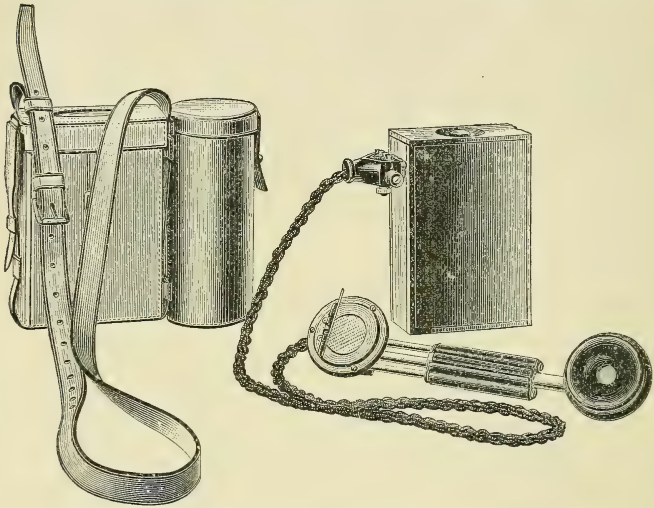


Fig. 501.—Ericsson's Portable Military Telephone Set

is peculiarly liable. For signalling a buzzer is preferred to a magneto-generator and bell, as although it makes sufficient noise to be heard by the attendant, the sound does not carry far enough to be heard by the enemy in its neighbourhood. Fig. 501 shows a very light and compact military set made by Messrs Ericsson, which was used by our army in South Africa with very satisfactory results. It weighs but 3·8 lbs., and is furnished with a telescopic hand-micro and waterproof 4-way connecting cord. Fig. 502 gives the connections of the instrument, and it will be seen that a double-spring push or

key is fitted, which when pressed connects the buzzer through the primary winding of an induction coil and a battery of two cells, and also connects the secondary winding directly to line, cutting out the receiver. This makes a very effective call, which will pass through very defective lines. The buzzer is also used for sending messages by Morse code signals. To prevent their being interpreted by the enemy, such messages are often sent in secret cypher. The Morse code is generally used when it is important that a message shall not be misunderstood, as with the telephone the sibilant sounds are liable to be mistaken. A condenser is joined across the

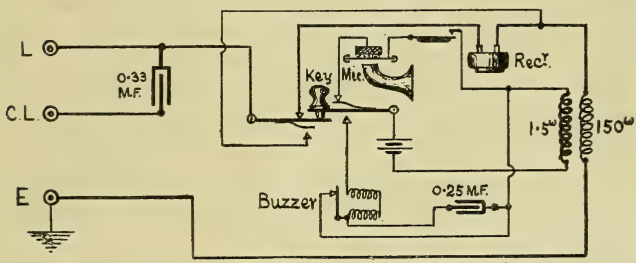


Fig. 502.—Connections of Military Telephone Set

contact breaker of the buzzer to prevent sparking, and another one is connected between line and terminal C L. This terminal is used instead of the L terminal when it is required to tap on an enemy's line, as then no direct earth is connected on line, and it cannot, therefore, be so easily detected.

Naval Telephones.—A great deal of use is made of the telephone on shipboard, especially on war vessels, where every part of the ship is connected to central points, so that information may be given and instructions obtained with the least possible delay.

The instruments used for naval purposes must be of the most substantial construction to withstand the very corrosive effect of sea-water and the shocks to which they are subjected. Certain instruments, such as those fitted in the conning-

towers of war vessels, must even be made bullet and splinter proof.

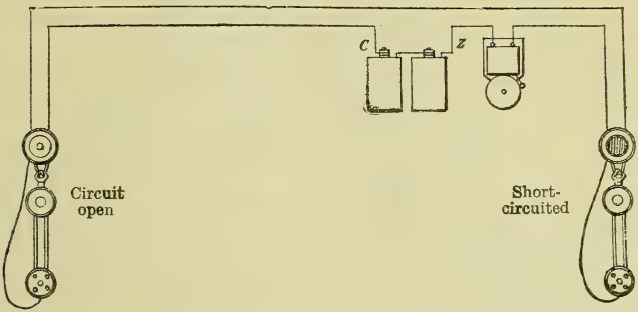
The whole of the parts are usually enclosed in brass or gun-metal outer cases, and the receivers are usually made of the fixed loud-speaking type, sometimes with hinged or pivoted tubular ear-pieces, which when not in use fold into recesses in the case, and sometimes without any ear-pieces at all. The opening for the transmitter is also closed watertightly when not being used.

Communication with Divers.—The helmets of divers are provided with transmitters and receivers, to which are attached insulated wires connecting to a telephone set in the attendant boat, so that continuous communication may be kept up between the diver and the men at the surface.

Traction Telephones.—In electric traction systems breakdowns are always liable to occur, and it then becomes of the greatest importance that communication may be obtained with a central station where breakdown apparatus and men are kept, so that the fault may be remedied, or the car removed with the least possible delay to traffic.

For this purpose a metallic circuit telephone line is run along with the feeder cable, and branch connections are made from this at frequent intervals, either to connecting-jacks, to which portable hand-micro-telephones can be connected, or to complete instruments, which need only be of a simple nature, as it is not necessary to ring from central office. Signalling is done by merely closing the loop circuit, which is normally open. This is done by the pressure of the hand spring on the hand-micro-telephones, this closing a circuit for a central battery and annunciator through a primary of an induction coil and the microphone, the receiver and secondary coil forming a local circuit, as shown in the common-battery circuit in Fig. 276 of Chapter XX. If it is required to ring some particular instrument on a line, such as a sub-office one, it can be done by connecting one coil of a repeater and a condenser in series in the line circuit and a polarised ringer in circuit with the other coil of the repeater.

Domestic Telephones.—By a simple arrangement a cheap form of telephone has been adapted for use in connection with ordinary electric-bell systems without interfering with the working of the latter. The instruments are of two types—one intended for fixing in the ordinary living-rooms of a house in connection with the push buttons, and the other for fixing in the kitchen or other servants' quarters in connection with the bell. The former class of instrument is so arranged that, when hung up or out of use, its circuit (which is a single one through receiver and microphone) is broken. Its 2-way



Dining-Room Fig. 503.—" Metaphone " Connections Kitchen

flexible cord is connected directly to the two terminals of the push button. The kitchen class of instrument is connected directly in series with the bell, and is so arranged that when hung up out of use it is short-circuited.

Fig. 503 shows the connections of a pair of "metaphones," which is the form of instrument extensively sold by the National Telephone Co. A special suspending hook is screwed to the push, and when the hand-micro is hung up by the loop the latter is pulled out slightly, and breaks the instrument connection. The "kitchen" instrument is attached to a terminal block, a suspending hook attached being connected to one of the cord conductors of the hand-micro; whilst the other cord conductor is connected to the loop

on the instrument, so that when hung up the instrument is short-circuited.

Signalling is done by the electric bell and push, and then on removing the instruments at each end instructions can be telephoned. An instrument can be connected to each push button.

The Telegraphone.—This is an instrument invented by Herr V. Poulsen of Denmark. It is analogous to the phonograph, inasmuch as it records speech and other sounds in such a manner that the sounds can be reproduced. In the case of the phonograph, the recording and reproducing processes are purely mechanical; whilst the telegraphone is worked magneto-electrically, and can be operated at a distance.

The principle on which the instrument acts is that of magnetising in varying strengths the successive points of hard steel wire, ribbon or disc, by driving it past the pole or poles of an electro - magnet, the winding of which is in the secondary circuit of an induction coil connected to a microphone. On speaking into the transmitter the induced currents from the secondary produce variations in the magnetic field of the electro-magnet, which causes the moving wire, etc., to be permanently magnetised in continually varying strength. When the steel wire thus magnetised is again passed in the same direction past the poles of the electro-magnet, which is now connected to a receiver, the varying magnetism is able to so vary the magnetic strength of the core as to produce electric waves in the coil wire, so that the receiver will exactly reproduce the original sounds, except as regards loudness. The record is of a permanent nature, and will, it is said, reproduce the sounds some 10,000 times without diminution, but, if desired, they can be at once obliterated by passing the record in front of the poles of a strongly magnetised electro-magnet, and the wire, etc., will then be ready for the impression of a fresh record.

The form of instrument which has been found the most useful is shown in Fig. 504. It consists of two large metal bobbins, either of which can be driven by an electric motor,

fitted in the case, so as to wind on a length of hard steel wire of about 2 mils diameter by unwinding it from the other bobbin. Between the other two bobbins the wire is guided close to the poles of two very small horseshoe electro-magnets—one of which, together with a second winding on the other one, is used for clearing the records from the wire; whilst the other winding of the latter magnet, of a resistance of 190 ohms, is used for recording and reproducing.

The bobbins contain a length of about 3·25 miles of wire,

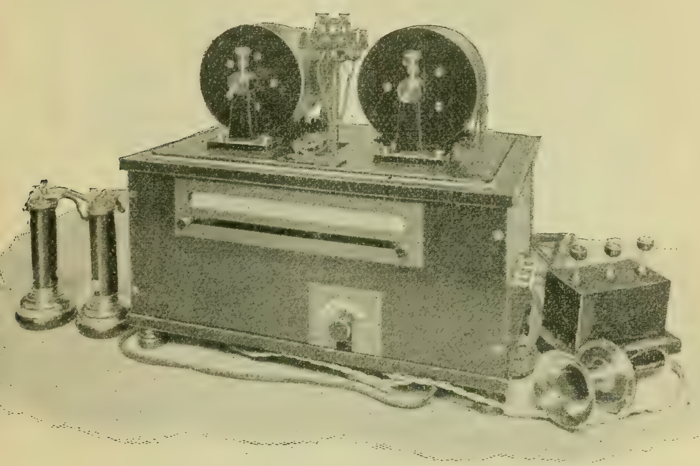


Fig. 504.—Poulsen's Telegraphone, Steel Wire Type

which is run past the magnets at the rate of about 10 feet per second, the length being sufficient for about 30 minutes of conversation.

When the record has been made the motor is switched over so as to drive the other bobbin, and rewind the wire on the same bobbin it was on at the start. The telephone receiver is then switched into connection in place of the transmitter, and the motor again switched on to drive the other bobbin, so as to reproduce the sounds.

It has been proposed to use the instrument for the recording

of conversations held over an exchange telephone line, the chief idea being that, if a subscriber is absent, the fact of his bell being rung automatically starts and switches in the telegraphone, and records the caller's message ready to be reproduced on the return of the subscriber.

There are certain difficulties, however, in connection with

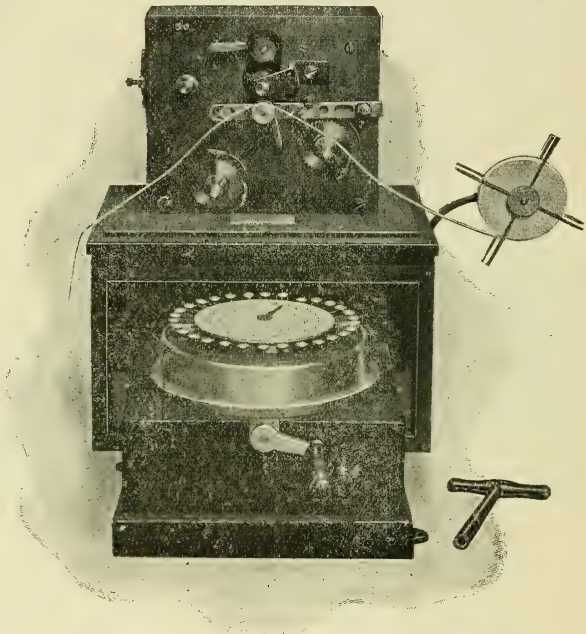


Fig. 505.—Stelje's Typewriting Telegraph

such use of the instrument—one of which is that, whilst the reproductions are remarkably clear and free from extraneous noises, the sounds are comparatively faint, so that, unless there are very favourable conditions in recording, the reproductions are too faint for practical use. Another important point is that the results are very poor on a common-battery circuit.

Stelje's Typewriting Telegraph.—This is a more practi-

cal instrument, used as an adjunct to an exchange telephone set, for the purpose of recording a message at another subscriber's office provided with a similar instrument. The record can be made in the absence of the subscriber, the recording apparatus at the distant end being started and driven by the magneto-electric currents generated by the transmitting machine. Fig. 505 gives a view of the complete

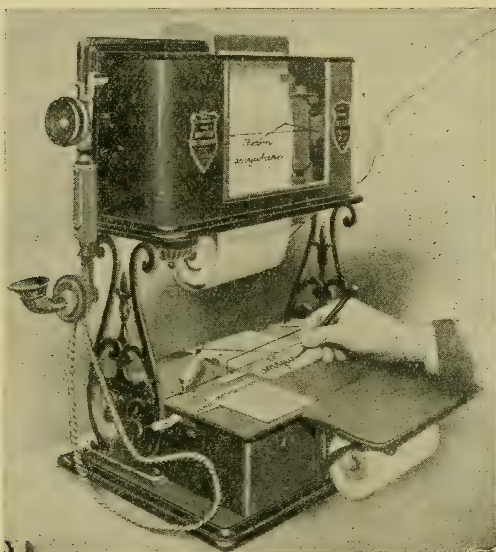


Fig. 506.—The Telautograph, General View

instrument, which is really a modification and improvement on the old Wheatstone A B C telegraphic instrument; a type wheel and tape machine being provided in place of the old circular indicating dial. The message is printed in type on the paper strip shown in the figure, and is ready for inspection on the return of the subscriber.

The Telautograph.—This is another very ingenious machine proposed as an adjunct to a telephone for the purpose of automatically registering the messages of subscribers. In this case

an exact facsimile of a message written at one end is made in ink at the other end, and not only writing, but sketches may be equally well transmitted. Thus, where extra security is desired, orders may be actually written and signed by the sender.

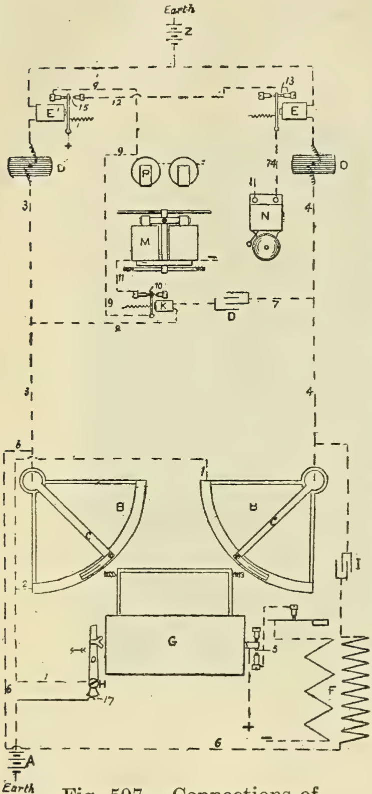


Fig. 507.—Connections of Telautograph

The instrument shown in Fig. 506 consists of a transmitter and receiver at each end, and the loop circuit is used as two single line and earth circuits.

The transmitting part consists of a pencil, to the lower end of which is attached, at a wide angle, two arms, which are themselves attached to the swinging arms of two sliding rheostats, shown at B, B in Fig. 507, by which resistances of from 0 to 7000 ohms may be inserted in the circuit of each line wire in varying proportions, according to the position of each of the two pencil arms.

The receivers are provided with a similar but lighter combination of arms connected to an inking pen, and to swinging coils in place of the rheostats, the coils being pivoted between the poles of horseshoe magnets, with intensifying iron cylinders like the coils of a D'Arsonval galvanometer. When a current is flowing through these movable coils they are turned on

their axes against the pull of directing springs, and to an extent proportional to the strength of the current, and, therefore, inversely proportional to the resistance inserted at the rheostats of the transmitter. The relative strengths of the currents in the coils determines the position of the recording pen at any time, which relative strength is continually altering as the transmitting pencil is moved over the face of the recording paper. In this manner the receiving pen is so guided as to trace an exact copy of the writing, etc., made at the transmitting end.

There are several other ingenious arrangements—such as for the purpose of lifting the recording pen off the paper, and for moving on the paper (which is in the form of a roll) when an

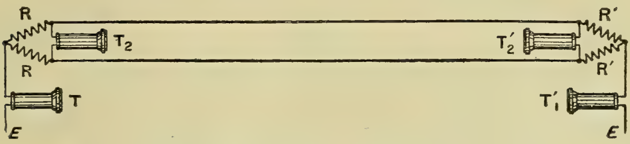


Fig. 508.—Multiplex Telephony Loop and Single Line from 1 Loop Circuit

exposed surface has been written upon. The former object is accomplished by the cessation of an alternating current obtained from an induction coil which is brought into action by the closing of a contact by the pressure of the transmitting pencil on a platen supporting the paper. This current passes through condensers round the loop, and works a relay, which in its turn works a magnet, which draws down the recording pen on to the paper. The moving of the paper is accomplished by another electro-magnet and relay, which is actuated when a certain lever is pressed by the transmitting pen, the current then acting through the two line wires in parallel and earth. An alarm bell is actuated through one leg only of the loop.

Multiplex Telephony.—By arranging resistances in connection with a loop line, in the manner shown in Fig. 508, two circuits may be worked independently,—No. 1 (T_1 and T_1'), as single line and earth circuit, and the other, No. 2 (T_2 and T_2'), as a loop circuit. In the former case, the two wires are used

in parallel as one of double size. The resistances R and R must be equal, as must also be R^1 and R^1, and it is also necessary that the wires composing the loop be properly balanced in regard to inductance, conductance, leakage, and capacity, or overhearing will ensue.

In earlier chapters several instances will be found where

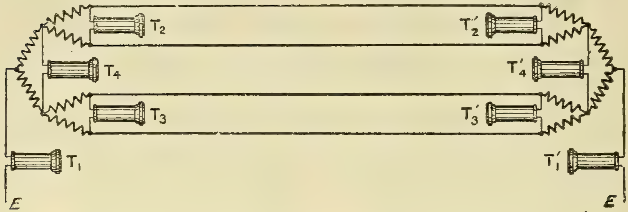


Fig. 509.—Multiplex Telephony, 3 Loops and 1 Single Line from 2 Loops

this form of *duplex* working is followed in connection with automatic signalling, etc., the resistances used being generally in the form of double or differentially-wound retardation coils, see Chapter XVIII. and page 490.

Fig. 509 shows how four circuits, three loops and one single, may be obtained from two metallic circuits, or four wires and resistances. This, however, is too complicated to work well

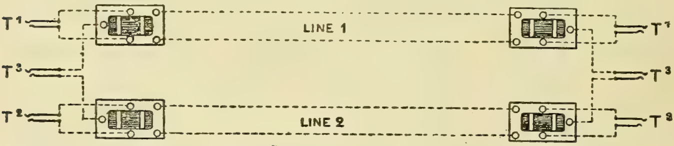


Fig. 510.—Multiplex Telephony with Repeaters, 3 Loop Lines from 2 Circuits

in practice, although three loop circuits are often obtained and used by omitting the four outer resistances. But for the difficulty experienced in keeping the balance such arrangements would be more frequently used. The plans shown were invented by Mr F. Jacob in 1882.

Fig. 510 shows a different and more frequently used arrangement, in which differentially-wound repeaters are used in

place of the resistance. The connection to the auxiliary circuit is then due to induction through the repeaters. The figure shows three circuits connected to branching-jacks, the centre jacks being for the auxiliary circuit.

In another system of multiplex working condensers are used instead of the repeaters, etc. Examples of this method of working also will be found in earlier chapters.

Simultaneous Telephony and Telegraphy.—The circuits in

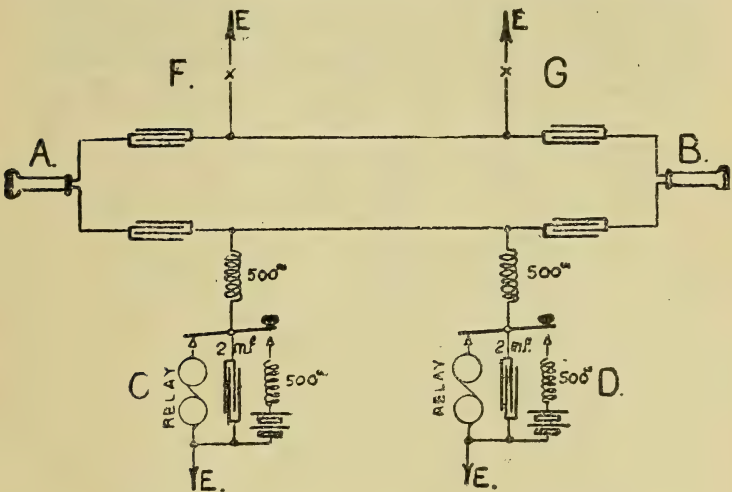


Fig. 511.—Combined Telegraphy and Telephony. Van Ryselberghe's System

multiplex telephony work quite independently of each other, so long as they are properly balanced, and any or all of them may be used either for telegraphic or telephonic purposes. The process of signalling which is referred to above is, in fact, a form of telegraphy. Such mixture of circuits is especially useful for railway working, as noiseless telephone circuits may be obtained from combinations of the ordinary telegraphic lines.

Van Ryselberghe System.—By the inclusion in the battery and line circuit of high inductance coils in a telegraph line, as shown in the lower part of Fig. 511, the suddenness of the make-and-break telegraph currents can be so reduced that a telephone connected in a branch circuit of a single-wire line would remain quite silent while telegraph messages were passing. As the telephonic speaking current will not affect the telegraph instruments, it was thus possible to work both telephone and telegraph on the same single-wire line, at the same time, quite independently. This system has been extensively used on the State telegraph lines in Belgium, and on a number of railway lines in other countries and for call-wire

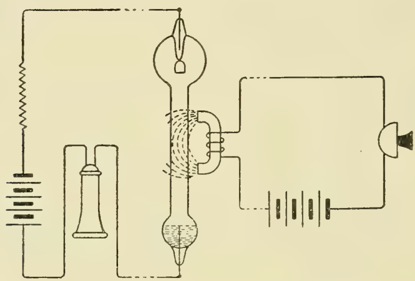


Fig. 512.—Telephonic Speech Relay. Cooper Hewitt's Mercury Vapour-Lamp System

circuits for trunk-line working by the British Post Office as described on page 490 of Chapter XXX.

By making the telephone return through a second telegraph line fitted in a similar manner (at both ends of course), as shown in the upper part of Fig. 511, it is easy to obtain an inductionless metallic circuit for the telephone, if the lines are properly balanced and twisted. The diagram has been simplified at the top, but it should be understood that the apparatus connected at points F and G is exactly similar to that shown at C and D.

Telephonic Relay or Repeater.—Many attempts have been made to introduce apparatus into a long line which should by some means reinforce the speech waves at that point and

send them forward to a distance. None of these attempts, however, have so far proved successful, as even if the loudness of the sound is increased the quality of the transmitted speech is very much affected, being so much distorted that it may not be understood at the receiving end. One of the most promising systems is that in which the mercury vapour-lamp of Mr Cooper Hewitt is used, as shown in Fig. 512. On speaking into the transmitter the speaking currents traverse the coils of an electro-magnet, in the magnetic field of which is the mercury vapour-lamp. The variations in the strength of the magnetic field cause corresponding variations in the resistance

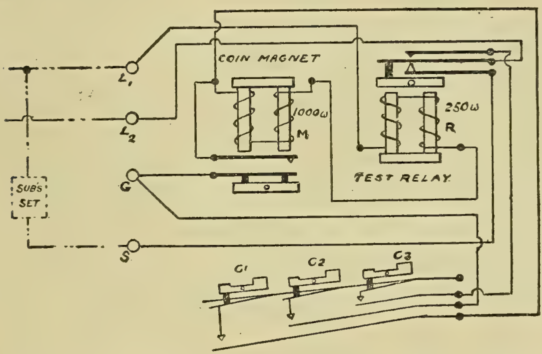


Fig. 513.—W. E. Co.'s Auto-Call Box Connections for 2d. and 3d. Fees

of the vapour arc, and intensified speech currents pass through the receiver shown. This arrangement is not yet in a practical form, as it can only be worked in one direction.

Automatic Call Boxes.—In all towns having a telephone exchange public call offices are provided into which any person may enter and on payment of certain charges be put into communication with another person connected on the exchange system. In most of the call offices special apparatus is provided which serves to collect and retain the money paid and provides certain checks so that the operator at the exchange may know that the correct fee has been deposited.

The Western Electric Co.'s type of auto-box is the latest form adopted and overcomes a difficulty met with in the boxes used previously, in which the fee to be paid was only deposited in the box after the number actually required was connected and ready to speak. The checking then entailed delay in completing the connection and acted as a serious drag on the operator. In the W. E. Co.'s form of box the caller has to deposit the fee before he can call the exchange, but provision is made for returning

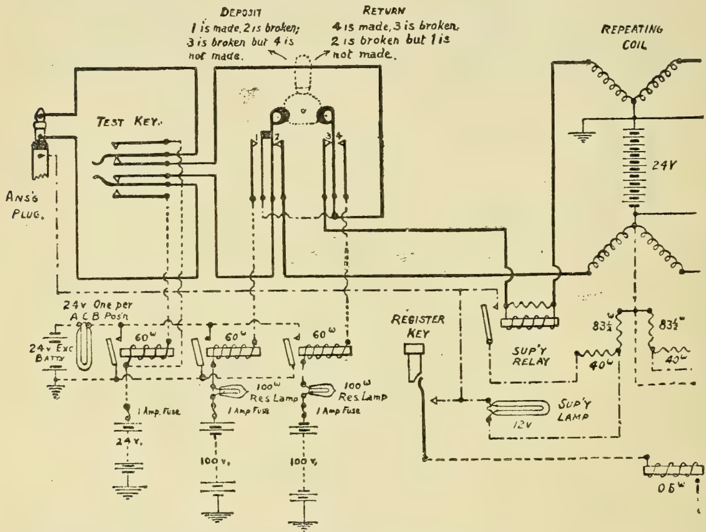


Fig. 514.—Operator's Connections for W. E. Co.'s Auto-Call Box

the coins to the caller in case the connection desired cannot be completed.

Fig. 513 gives the connections of a box arranged for an ordinary fee of twopence and for an extra penny for a special call. The two pennies when put in the shoot run down and come to rest in a position where they press the contacts C_1 and C_2 against the two springs S_1 and S_2. This closes the "A" line circuit to earth (or G) through the coin magnets and test relay and operates the calling lamp at the exchange. The operator answers

in the ordinary manner but uses a cord in the answering side of which is the special apparatus shown in Fig. 514. If the call is an ordinary fee one, she completes the call, if possible, in the usual way, and the clearing signal is also given in the usual manner when the receiver is hung up. If, however, the call cannot be completed she informs the caller and operates the "return or deposit" key shown, so as to return the coins to an outer receptacle. This key sends current from a 100-volt earthed battery through the "A" line and the coin magnet at the box; the test relay, etc., being cut out after the first movement by the contact on the double armature spring. The coin

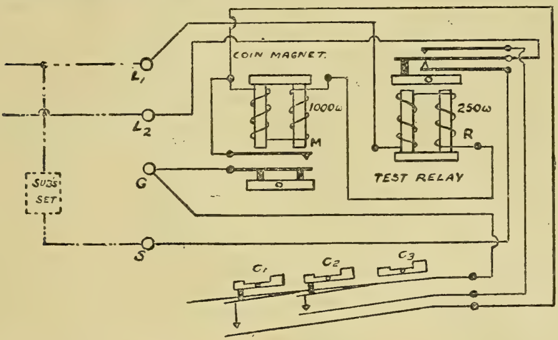


Fig. 515.—W. E. Co.'s Auto-Call Box. Connections for 1d. and 2d. Fees

magnet is a polarised one and the coin shoot is pivoted and attached to the armature. Under normal conditions the end of the shoot is in an intermediate position between two slots, one of which leads to the cash-box and the other to a return receptacle outside the box. A positive current moves the shoot to the "cash-box" slot and a negative one to the "return" slot and at the same time the lamp L glows to show that the coins were deposited. If not returning the coins the operator operates the deposit key after receipt of clearing signal but before clearing the cords.

Should the special fee be necessary for the call the operator asks the caller to deposit the extra penny and before complet-

ing the connection tests if this has been done by pressing on the "test-key" shown, which sends a positive 24-volt current through the "A" line, operating the polarised test-relay so as to connect spring C_3 (Fig. 514) to the "B" line, through which a positive current is also sent if the coin is deposited, and this causes the operation of the lamp L. The test-relay in the box is made a polarised one so that it shall not be operated by the calling current.

Fig. 515 shows the modifications necessary in the box if the ordinary fee is one penny.

APPENDIX

Double-Jack Party-Line Working. — On the latest C.B. exchange equipments two jacks are fitted and allotted among the ordinary multiple jacks for each party line; one jack being used for the subscribers who are rung on the "A" wire and the other for those on the "B" wire of the line. These are for the purpose of enabling the operators when calling up a party-line subscriber to be able to call them just as she does an ordinary subscriber and without having to resort to some special reversing key as was necessary with the old method. Fig. 516 shows how these jacks are connected. Only one calling lamp and answering jack are needed at the home or answering position, but it will be seen that by jumper connections on the intermediate distributing frame two sets of jacks are connected up on the multiple, the upper set having the "B" wire connected to the tip spring, the lower set having the "A" wire connected to the tip spring.

These reversed jacks enable the subscribers on 2-party lines to be rung up in exactly the same manner as with an ordinary direct line subscriber, also to have any number allotted to them, and also to retain their number if they should move to another part of the town or take direct or individual lines. With 4-party or more lines the double jacks are also used, but it is then necessary to call by code which is indicated by the markings on the jacks. The adoption of the double jacks has resulted in much more efficient working.

The Ericsson Central Energy System.—This system has not at time of writing been introduced into this country, but is used to a considerable extent on the Continent and has recently been selected for the principal Paris exchange.

Fig. 517 shows the principal points of the system, which is based on the Stone system of C.B. working. Two stations A_1 and A_2 and lines are shown connected to the exchange, with the line calling apparatus and a pair of connecting cords at the latter.

On a subscriber lifting up his receiver a circuit is completed for the 20-volt central battery through retardation coil R_2, line, instrument, line and coil of line relay R_1 to battery. Arma-

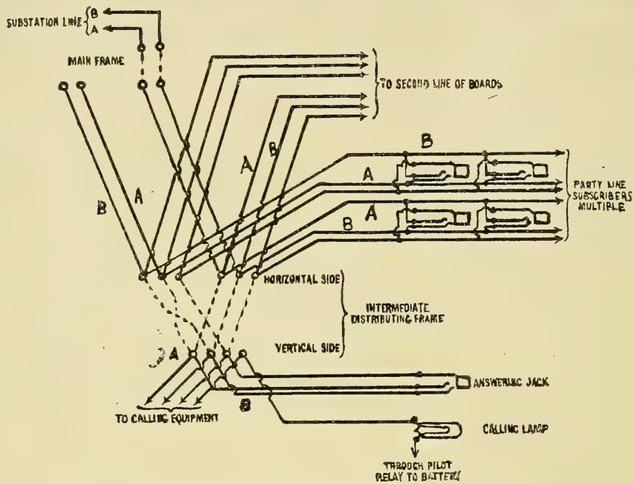


Fig. 516.—Connections for Double-Jack Party-Line Working

ture of line relay closes contact S, completing battery circuit through contact of cut-off relay UR, lamp AL, pilot relay (not shown) and earth back to battery. The operator then inserts answering plug AP into answering jack LJ, which closes a momentary battery circuit through supervisory lamp (or lamp relay) SL, sleeve contact of answering plug AP, socket of answering jack LJ, coil of cut-off relay UR to earth. The armature of UR is attracted and the calling lamp (or relay) is cut off, and at the same time the supervisory lamp is short-circuited by the front contact of UR relay and a new battery circuit

completed through contact S for the coil of relay UR. The connection to the called-for subscriber is completed in the

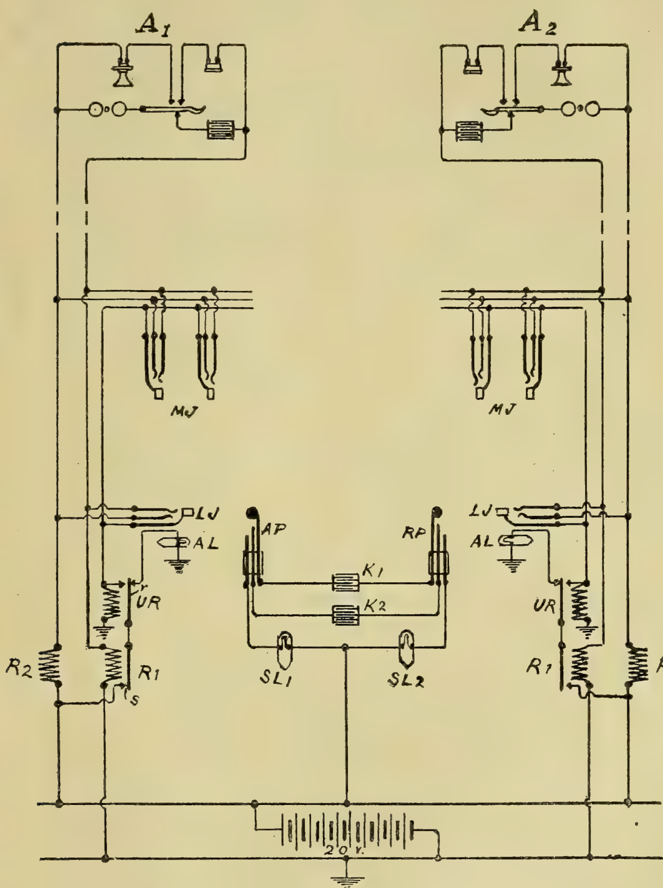


Fig. 517.—Connections of L. M. Ericsson's C.B. System

usual manner by connecting into one of the multiple jacks MJ, and the speaking circuit is completed through two condensers. The operator is provided with combined listening and ringing

keys, and the latter keys are arranged for automatic working.

The current for speaking is fed through coils R_2 and R_1, and is not interrupted so long as the receiver is off the hook at the subscribers' instrument, so that the annoying clicks which are heard in other C.B. systems are absent in the Ericsson one.

Whilst the receiver is off the hook the supervisory lamp (or relay) SL is short-circuited by front contact of cut-off relay UR, but on hanging up the receiver the battery circuit through relay R is broken, contact S is opened, and the short-circuit removed from the supervisory lamp, which in consequence glows.

For the engaged test the operator's headgear receiver is differentially wound with a centre connection to earth or to the negative side of the battery. On touching the socket of jack with the tip of connecting plug a click is heard if line is engaged owing to the completion of a battery circuit.

Measured Service Working.—Fig. 518 gives the line connections at the top and the cord connections at the bottom for the system when arranged to work on the measured rate service. The same letters are used to designate the various parts as in Fig. 517, but a lamp relay is shown in connection with the supervisory lamp. A manual register key MK is used which is depressed on completing the call, this completing a battery circuit through contact S of relay R_1, lower contact of relay UR, coil of register CC, bush of answering jack LJ, sleeve of plug AP, contact *v* of combined speaking and ringing key SRK, register key contact, relay coil MR to earth. The register CC lever remains in position until the contact *v* on SRK key is broken, so that only one call can be registered however many times the key MK may be pressed. OC is a counter common to a position which is operated at the same time.

The Egner and Holmström Transmitter.—With this transmitter it is claimed that on long distance circuits on the Continent of Europe, transmission results equal to twice those of any other transmitter have been obtained, and this claim appears to be to a large extent substantiated.

A patent granted in 1908 (No. 6587) to the same persons was

connected with an arrangement of the granule cell of a transmitter which was to be made air-tight, and the air in the cell was to be replaced by a better heat and electrical conductor, such as coal gas or other hydrocarbon gas, so that a stronger

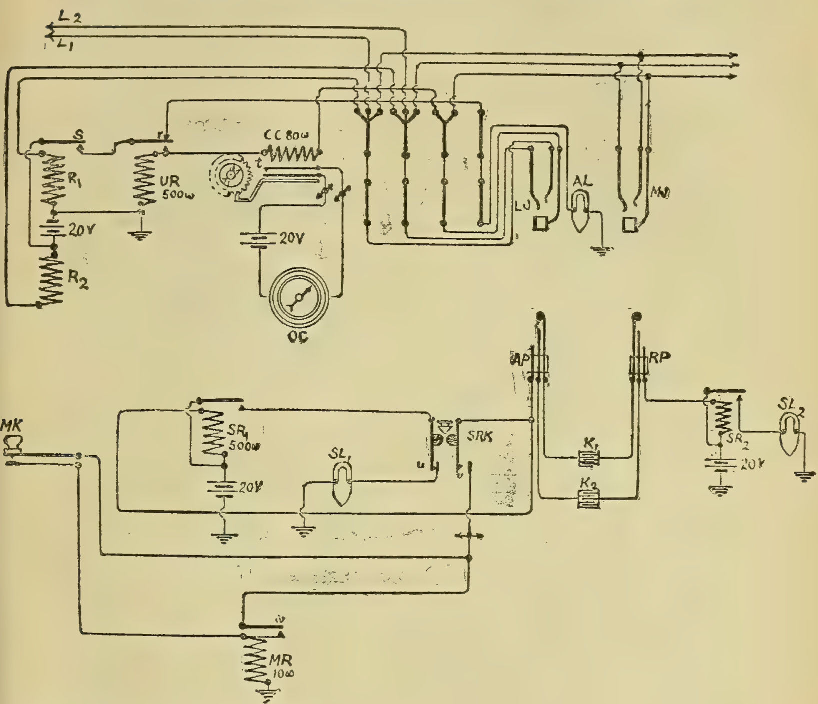


Fig. 518.—L. M. Ericsson's C.B. System arranged for Measured Rate System

current could be passed through the cell and the heat generated be rapidly dissipated.

A later patent specification (No. 12,918 of 1909) describes methods of stretching the diaphragms so as to ensure that the greatest amplitude of vibration shall be at its centre, and also of so connecting subsidiary diaphragms for the granule cells to the centre of the main diaphragm as to ensure a maximum

vibration in the microphone cell or cells. Fig. 519 shows one of the arrangements given, the fly nut on the top left side being one of about 6 used to screw down a rimmed edge of a round collar (shown only in section) on to a portion of the edge of the diaphragm which comes between the two edges of a recess in the circular frame. One of the micro-

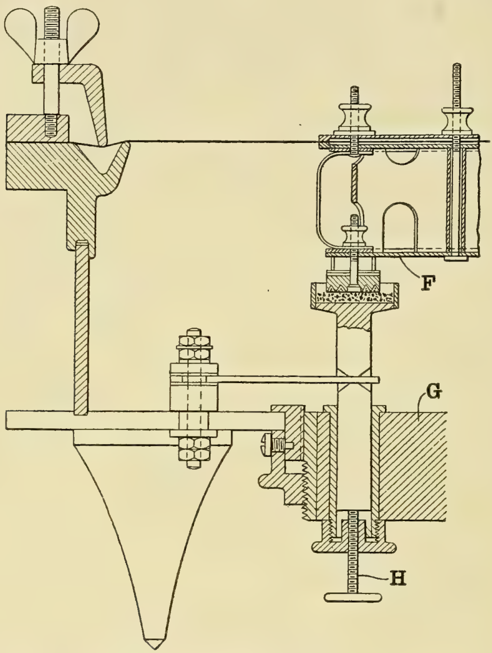


Fig. 519.—Egner and Holmström Transmitter
(*By permission of the Proprietors of* Electrical Engineering)

phone cells only is shown with a spring and screw arrangement for adjustment. For further particulars see *Electrical Engineering* for 7th October 1909, also *The Electrician*, 19th November 1909.

The Mercury-Arc Rectifier.—This is now used in several of the National Telephone Co.'s exchanges where the outside supply is alternating, and has given very good results.

Its action depends on the fact that mercury vapour in a

vacuum tube at a certain pressure is a good conductor for current in one direction but almost an insulator for current in the reverse direction, so that if an alternating current be connected directly to the tube whilst an arc is maintained only one half of the wave will be transmitted through the tube, the other half being suppressed. By arranging a mercury vapour tube in the manner shown in the centre of Fig. 520 with a transformer in the supply circuit to reduce the voltage to that required for the batteries (viz. 30), both parts of the alternating waves can be utilised and the current rectified in a very simple, silent, and highly efficient manner. The storage battery is shown at J joined to the tube at B. The connection at C is for the purpose of starting the arc, the tube being tilted so as to flow a small quantity of mercury over connections B and C and then tilted back. The arc is maintained by self-induction sparks from the coils F and E, and one half of any one wave flows through one of the coils and the other half through the other. The connection at C is broken after starting.

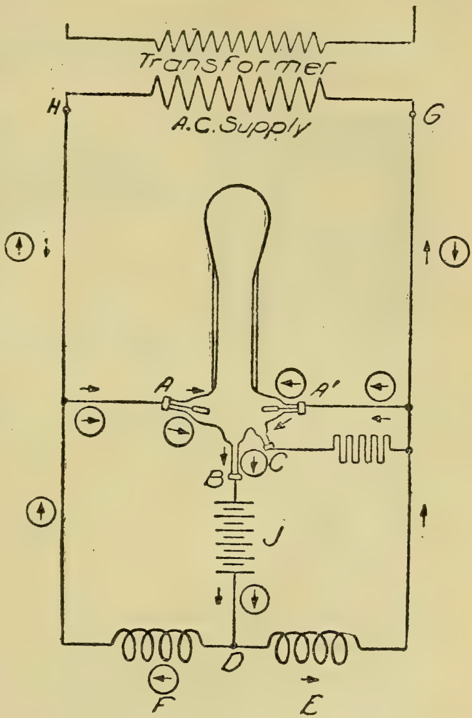


Fig. 520.—Mercury-Arc Rectifier

The efficiency of the apparatus ranges from about 76 % at one quarter of full load and upwards.

For further particulars the reader is referred to an article by Mr J. R. Milnes in *The National Telephone Journal* for March 1908.

New Pattern Instrument Plug and Jack.—Fig. 521 shows new patterns of instrument plug and jack which are used in con-

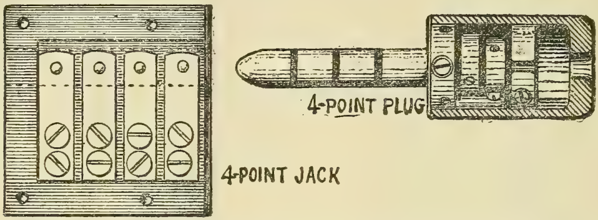


Fig. 521.—New Form of Instrument Jack and Plug (Scale ½)

nection with switch-boards for connecting the operators' instruments, in place of the patterns shown in Figs. 97 and 98, as being neater and more compact. The connections to the different sections of the sleeve of the plug are made through concentric metal tubes to the connecting rings shown at the back. When the plug is properly inserted into the hole in the jack, shown by dotted lines, the springs of the jack press on the several sections of the sleeve of the plug.

Calculation of Capacity and Inductance of Lines.—If $h =$ height above the ground of a single wire and earth aerial line; $r =$radius of section of wire; $d =$distance between the centres of wires of an aerial loop line; and $K =$the capacity in farads per mile; then

For a *single wire* line, $K = \left(\dfrac{0{\cdot}03884}{\log_{10}\dfrac{2h}{r}}\right)10^{-6}$

For a *loop line*, $K = \left(\dfrac{0{\cdot}01942}{\log_{10}\dfrac{d}{r}}\right)10^{-6}$

Inductance L in henrys per mile.

For a *single wire* line, $L = \left(0{\cdot}08045 + 0{\cdot}7421 \log_{10}\frac{2h}{r}\right)10^{-3}$

For a *loop* line, $L = \left(0{\cdot}1609 + 1{\cdot}482 \log_{10}\frac{d}{r}\right)10^{-3}$

h, d and r must all be in the same units.

The above are theoretical values for isolated wires, and the values may be modified from 5 to 20 per cent. by the proximity of other wires.

Mansbridge's Foiled Paper Condensers.—Instead of using separate sheets of tin-foil and paper, as in the ordinary method of constructing condensers for telephone purposes, foiled paper similar to that used for wrappers of tea, etc., is used of special manufacture so as to render it of better conductivity and uniformity. The condensers are made from two continuous coils of this paper interleaved with two strips of very thin plain paper, these four strips being rolled together to the length necessary to give the capacity required. The roll is then taken off the mandrel, thoroughly dried, then impregnated with paraffin wax and afterwards compressed into a flat shape, the block thus obtained being next hermetically sealed in a tinned iron case. By this means it is claimed that much more compact condensers can be obtained at about one-tenth the cost of the tin-foil patterns. They are now extensively used in telephony and telegraphy.

For full particulars see Mr G. F. Mansbridge's paper on "The Manufacture of Electrical Condensers," read before the Institute of Electrical Engineers on 7th May 1908.

For a very valuable paper on "The Condenser in Telephony," by Mr G. M. B. Shepherd, see *Electrical Engineering* for 5th November 1908.

NOTES ON TRAFFIC

The *Average Number of Calls per Direct Line* are in London 10·5 and in New York 9, per day, the smaller number being accounted for by the greater proportion of Message Rate subscribers in New York.

The *Time of Answering* in New York averages 3·6 seconds, in Nottingham it is 3·8, and in Edinburgh 3·5 seconds.

Time of Disconnecting in New York has been reduced from an average of 17·1 to 3·08 seconds by the adoption of the relay and lamp working and improved supervision. In Nottingham it is 3·7, and in Edinburgh 3·7 seconds.

The proportion of *Found Busy* cases in New York has fallen from 23 to 12·5 per cent. of the calls, owing to the number of message-rate lines and to greater celerity in clearing.

In some "relay" exchanges in this country it has been found by frequent tests that

99	per cent.	of the calls	are answered	in less than	5	seconds
93	„	„	„	„	4	„
85	„	„	„	„	3	„
76	„	„	„	„	2·5	„
55	„	„	„	„	2	„

The average time being 2·7 seconds.

In some "magneto" or "generator calling" exchanges

88	per cent.	of the calls	are answered	within	5	seconds
83	„	„	„	„	4	„
68	„	„	„	„	3	„
55	„	„	„	„	2·5	„
39	„	„	„	„	2	„

The average time being 3·5 seconds.

AGREEMENT BETWEEN BRITISH POST OFFICE AND NATIONAL TELEPHONE CO. LTD.

Specification and Rules as to Plant.

1. *Definitions.*

In this Schedule—

The term "Exchange Subscriber's Circuit" or "Circuit of an Exchange Subscriber" means the wires and apparatus connecting a call office or a subscriber's office (whether on an exclusive line or a party line) with an exchange and the term "Junction Circuit" means the wires and apparatus which connect any two exchanges in the same exchange area or an exchange and a prescribed post office in the same exchange area.

The term "Test Cable" means a telephone dry-core cable the wires of which have a loop resistance of 88 ohms per mile and an average mutual electrostatic capacity of 0·054 microfarads per mile between wire and wire of each pair and an average insulation of not less than 200 megohms per mile between wire and wire of each pair all measurements being made at 60° Fahrenheit.

The term "Test Instruments" means common battery instruments fed by a battery of 22 volts through a circuit which except so far as it consists of exchange apparatus and Subscribers' Instruments shall have a resistance of 300 ohms (all being in accordance with the specification and diagram identified in duplicate before the execution of this Agreement by the signa-

tures of the Engineer-in-Chief to the Post Office and the Engineer-in-Chief to the Company).

2. *Circuits.*

(1) All circuits whether exchange subscribers' circuits or junction circuits shall be metallic.

(2) All circuits when used for speaking on local exchange lines or through to a trunk circuit which itself is free from disturbance shall be free from inductive or other disturbances.

(3) All circuits shall be so arranged that each exchange subscriber shall be unable to overhear what passes on any other than his own circuit or those to which it is joined through.

3. *Conductors.*

The use of iron conductors shall not be permitted in any portion of a circuit.

4. *Cables.*

(1) All buried cables shall be efficiently protected by iron pipes or by ducts of glazed earthenware laid in concrete or by cement blocks thoroughly matured or by such other means as the Postmaster General may approve before the cable is laid.

(2) Cables in subways or tunnels shall be supported in such a manner as to prevent fracture of the lead covering.

5. *Overhead and Underground Plant.*

(1) Distributing wires (that is wires from a distribution point of exchange subscribers' offices) may be carried either overhead or underground as may be considered desirable and overhead distributing wires may either be open or be contained in a cable.

(2) No overhead wire extending more than a quarter of a mile from a distribution point shall be considered to be a distributing wire.

(3) Wires other than distributing wires may be carried overhead—

(*a*) Either open or in lead-covered cables Provided that on one line of poles or other supports not more than 104 wires in all may be carried of which only 64 may be open.

(*b*) In cables of any kind across a river canal estuary or railway or across overhead electric wires used for the purpose of lighting traction or the transmission of power.

(4) Wires other than distributing wires may be carried overhead either open or in cables without reference to the limitation contained in the last preceding sub-clause—

(*a*) In connection with any exchange system or part of an exchange system which at the date of this Agreement consists substantially of overhead lines (a list of which exchange systems and parts of exchange systems has been furnished by the Company to the Postmaster General and is identified by the signatures of the Secretary to the Post Office and of the General Manager of the Company) Provided that—

(i) in no case shall more than 104 circuits or 208 wires be carried in cables on any one line of poles or other supports to be hereafter erected or more than 104 circuits or 208 wires be hereafter added in cables to any one line of poles or other supports now existing; and

(ii) all cables hereafter erected shall be lead-covered when practicable; and

(iii) the case of each exchange system or part of an exchange system which is specified in the aforesaid list and which is established in a town having a population of 50,000 inhabitants and upwards according to the last census shall if the Company so request be specially considered and in respect of each such exchange system or part of an exchange system the Postmaster General shall notify the Company within six calendar months from the date of the Company's request

whether he is prepared to provide from time to time such underground works as the Company may require for extending or adding to such exchange system or part of an exchange system on a systematic plan and in default of his giving to the Company an assurance to provide such works the first preceding proviso to this sub-clause shall not apply in the case of such exchange system or part of an exchange system.

(*b*) In cases where the Company are unable to execute underground works by virtue of any powers which they may possess or are unwilling to execute such works in consequence of the terms and conditions proposed by a local authority and the Postmaster General (whether the Company possess such powers as last aforesaid or not) after application to him by the Company in that behalf refuses or fails to agree within a reasonable time to provide the underground works specified in the Company's application.

(5) Except as aforesaid no wires of any kind shall without the consent in writing of the Postmaster General be carried overhead.

6. *Test of Audibility.*

All instruments wires and apparatus shall be such that the transmission of speech thereby shall not be inferior in audibility to that afforded by test instruments connected by a length of test cable in accordance with the following regnlations :—

(1) When—

(*a*) any two exchange subscribers' circuits are connected together on the same exchange or

(*b*) the circuit of an exchange subscriber whose office is on one exchange in an exchange area is connected with the circuit of another exchange subscriber whose office is on a different exchange in the same exchange area and the radial distance between the two exchanges does not exceed ten miles.

The standard of speech shall not be inferior to that afforded by test instruments connected by a length of twenty miles of test cable :

Provided that where an exchange subscriber's office situate more than five miles from an exchange is connected with another exchange subscriber's office situate more than five miles from another exchange the standard of speech between such offices shall be deemed satisfactory if not inferior to that afforded by test instruments connected by a length of twenty-five miles of test cable.

(2) When the circuit of an exchange subscriber whose office is on one exchange in an exchange area is connected with the circuit of another exchange subscriber whose office is on a different exchange in the same exchange area and the radial distance between the two exchanges exceeds ten miles but does not exceed fifty miles the standard of speech shall not be inferior to that afforded by test instruments connected by a length of thirty miles of test cable :

Provided that where an exchange subscriber's office situate more than five miles from an exchange is connected with another exchange subscriber's office situate more than five miles from another exchange the standard of speech between such offices shall be deemed satisfactory if not inferior to that afforded by test instruments connected by a length of thirty-five miles of test cable.

(3) When the circuit of any exchange subscriber is connected to a prescribed Post Office in the same exchange area for the purpose of being connected to a trunk wire of the Postmaster General the standard of speech through the exchange subscriber's circuit and the junction circuit or circuits combined (exclusive of the trunk wire) shall not be inferior to that afforded by

test instruments connected by a length of five miles of test cable.

Provided that where the radial distance between a prescribed Post Office and an exchange when added to the radial distance between an exchange subscriber's office and the same exchange exceeds nine miles the standard of speech through the exchange subscriber's circuit and the junction circuit or circuits combined (exclusive of the trunk wire) shall be deemed satisfactory if not inferior to that afforded by test instruments connected by a length of eight miles of test cable.

7. *Exchanges.*

All new and reconstructed exchanges shall be provided with automatic calling and clearing apparatus on every exchange subscriber's circuit and the calling and clearing signals shall be effective in all conditions and upon the longest circuits used in an exchange area when connected together.

Provided that automatic calling and clearing apparatus need not be provided in any new or reconstructed exchange designed for an ultimate maximum capacity of not exceeding one thousand direct subscribers' lines and a fitted capacity of not exceeding 400 such lines if in any such case a thoroughly efficient method of calling the exchange and signalling the close of a conversation is provided.

8. *Exchange Equipments.*

In exchange equipments on the multiple system the multiple jacks shall be connected on the branching system except in cases in which not more than ten jacks are in series.

9. *Junction Circuits.*

Junction circuits connecting exchanges with prescribed post offices shall be provided with automatic signalling

arrangements of a character approved by the Postmaster General and suitable for working in connection with his trunk lines and shall be worked in accordance with such regulations as he may from time to time prescribe.

10. *Subscribers' Instruments.*

The apparatus fitted at exchange subscribers' offices shall be efficient for trunk line communication and where separate batteries are provided at each exchange subscriber's office for speaking purposes the electro-motive force shall not at any time fall below two volts and such apparatus shall be so fitted as to admit of a clearing signal being transmitted by the exchange subscriber to the prescribed Post Office to indicate the close of a trunk conversation.

11. *Notice of New Equipment.*

With a view to avoid difficulty under the last two preceding clauses the Company shall at least six calendar months before the bringing into use of a new exchange equipment in an exchange furnish the Postmaster General with diagrams illustrating both the exchange subscribers' circuits and the method by which it is proposed to actuate the signals on the junction circuits at the prescribed Post Office.

12. *Protection of Circuits.*

Where an overhead electric system used for the purpose of lighting traction or the transmission of power is worked in the neighbourhood of any overhead circuits of the Company suitable safety devices including fuses and heat coils shall in all circuits likely to be affected be provided both at the exchange and at the exchange subscribers' offices.

13. *Lightning Protectors.*

Efficient lightning protectors shall be provided on all circuits.

With regard to the above specification Mr Gavey, the Engineer-in-Chief to the Post Office, stated in his evidence before the Select Committee of the House of Commons that . . . "the present specification provides a defined and scientific method of measuring results, instead of specifying definite conditions which might not under all circumstances be applicable."

. . . "this method provides for attaining thorough efficiency in the most economical manner possible; in every case it will be the duty of the engineer in charge to make a thorough study of his telephone area before laying down new or renewing old plant. He will proportion the size and therefore the cost of his conductors to the conditions he has to meet, and he will be in a position to provide an effective service at the least possible capital expenditure."

TABLE OF EQUIVALENT LENGTHS OF LINE AND LIMITING DISTANCES FOR COMMERCIAL SPEECH

Type of Line	Constants per Mile of Loop			Equivalent Lengths in Miles Calculated	Limiting Distances for Commercial Speech	
	R Ohms	K M.F.'s	L Henries		Calculated	Experiment
Underground				Miles	Miles	Miles
10 lb. Cable	175·64	·07	·001	0·61	26	26
20 ,, ,,	86	·055	·001	1	43	43
40 ,, ,,	42	·056	·001	1·47	63	63
70 ,, ,,	25	·063	·001	1·83	79	
100 ,, ,,	17	·058	·001	2·45	105	
150 ,, ,,	11·7	·065	·001	2·95	127	127
200 ,, ,,	8·75	·07	·001	3·5	151	
Submarine Cable						
160 lb.	12·9	·12	·00165	2·3	99	88
Aerial Lines						
100 lb. Copper	18	·00808	·0039	8·45	363	
150 ,, ,,	11·9	·00839	·00376	11·7	503	473
200 ,, ,,	9	·00862	·00366	14·7	632	626
300 ,, ,,	6	·00893	·00355	21	903	903
400 ,, ,,	4·5	·00919	·00344	26·1	1122	1075
600 ,, ,,	2·97	·00958	·00331	36·8	1582	1582
800 ,, ,,	2·25	·00987	·00322	45·8	1969	

The above table is taken from the Presidential Address of Mr J. Gavey to the Institution of Electrical Engineers on 9th November 1905. Columns 5 and 6 have been calculated from the formulæ of Professor Pupin for attenuation in the case of the cable lines where leakage can be neglected, and from that of Professor Campbell in the case of aerial lines—the latter formula taking into account the insulation, at the rate of 1 megohm per mile.

The unit in this table is the Standard Cable described on pages 83, 413, and 513.

The Table of Equivalents will be found of great value in the economical design of circuits to fulfil any required standards, the numbers given in column 5, or their reciprocals, being used as factors in connection with any particular class of line.

The following table, also taken from Mr Gavey's address, gives results obtained by the Bell Telephone Companies in America, with a comparison of the London - Birmingham underground cable. It also shows how the so-called K.R. law, in which no account was taken of inductance, has failed to justify itself.

TABLE OF EQUIVALENT LINES

Type of Line	Ohms per Mile of Loop	Mutual Capacity of Loop in M.F.'s	Long Distance Standard of Speech		Local Standard of Speech	
			Length in Miles	K.R.	Length in Miles	K.R.
Copper						
100 lb. Aerial	17·73	·007825	388	20,884	253	8,880
176 ,, ,,	10·26	·008218	560	26,443	360	10,927
425 ,, ,,	4·08	·008978	1200	51,027	750	20,604
Cable						
American Standard	88	·051	41·8	7,842	26	3,304
Boston-Lynn	41·8	·041	73·2	9,407	45·5	3,635
London-Bir'gh'm	11	·063	115	9,165	71·5	3,543

TELEPHONES IN VARIOUS COUNTRIES

On 1st January 1909

Country	Population in Millions	Telephones	Inhabitants per Telephone	Telephones per 1000 Inhabitants
United States .	88·1	6,870,000	13	77
German Empire .	60·4	851,319	71	14·1
Great Britain and Ireland . .	43·5	565,854	77	13
France . .	39·2	194,159	202	5
Canada . .	6·0	160,000	37	27
Sweden . .	5·3	156,000	34	29·4
Austria-Hungary .	26·1	124,825	209	4·8
Russia . .	149·4	113,000	1,322	·76
Japan . .	49·4	71,430	691	1·45
Switzerland .	3·0	69,122	44	22·7
Denmark . .	2·5	67,339	38	26·3
Norway . .	2·3	53,726	43	23·2
Italy . . .	33·5	53,721	625	1·6
Australia . .	4·0	50,600	79	12·7
Holland . .	5·6	48,134	117	8·5
Belgium . .	7·2	38,503	188	5·3
Argentine Republic	7·0	30,000	233	4·3
New Zealand .	·96	25,924	37	27
Spain. . .	18·6	19,500	955	1·05
Roumania . .	6·6	11,500	573	1·7
India . . .	240·5	8,203	29,318	·034
South Africa .	7	7,736	905	1·1
Egypt . .	11·52	7,025	1,640	·61
Portugal . .	5·4	5,000	1,085	·92
Luxemburg .	·25	3,000	82	12·2

TELEPHONES IN LARGE CITIES

On 1st January 1909

City	No. of Telephones	City	No. of Telephones
New York . . .	326,907	Glasgow	43,928
Chicago	169,134	Hamburg . . .	41,809
London	164,208	Cincinnati . . .	41,180
Berlin.	139,622	Buffalo	40,125
Philadelphia . . .	128,345	Pittsburg . . .	38,805
Boston (U.S.A.) . .	109,300	Copenhagen . . .	37,723
St Louis	73,836	Baltimore . . .	37,498
Stockholm . . .	70,011	Detroit	37,232
Paris	65,033	Vienna	35,011
Cleveland (U.S.A.) .	51,964	Washington . . .	33,251
San Francisco . .	48,533	Los Angeles . . .	32,816
Kansas City . . .	46,006	Minneapolis . . .	31,000

TELEPHONES IN LARGE CITIES—*continued*

City	No. of Telephones	City	No. of Telephones
Milwaukee	27,891	Spokane	14,521
Indianapolis	27,027	Warsaw	14,000
Liverpool	26,849	Buda Pest	13,906
Denver	26,012	Stuttgart	13,750
Seattle	24,198	Birmingham	13,479
Toronto	24,182	Brussels	13,348
Montreal	24,021	Dallas (Texas)	13,020
Columbus (U.S.A.)	23,850	Toledo (U.S.A.)	13,000
Moscow	23,000	Breslau	12,619
Munich	22,160	Atlanta	12,253
Portland (U.S.A.)	22,098	Jersey City	12,133
St Paul (U.S.A.)	22,000	Winnipeg	12,000
Manchester	21,209	Louisville	11,681
St Petersburg	20,000	Gothenburg	11,241
Omaha	19,289	Worcester (U.S.A.)	11,150
Frankfurt	19,230	Sydney	11,000
Providence	18,721	Edinburgh	10,889
Tokio	18,589	Düsseldorf	10,841
Leipzig	18,556	Hull	10,800
Buenos Aires	17,500	Amsterdam	10,660
Oakland (California)	16,639	Nuremberg	10,653
Dresden	16,623	Syracuse (New York)	10,521
Cologne	15,686	New Haven	10,483
Newark (U.S.A.)	15,572	Richmond (U.S.A.)	10,152
New Orleans	15,473	Grand Rapids	10,100
Christiania	15,198	Hartford (U.S.A.)	10,052

The above tables are abstracted from a series of articles on "The Telephone Stations of the World," by Mr W. H. Gunston, published in *The National Telephone Journal* for July to November (inclusive) 1909, and to these articles the reader is referred for full information.

Of the 76 cities given in the last table, 40 are in the United States, 11 in the British Empire and 11 in the German Empire.

TABLE OF THE EFFECTIVE RESISTANCE, INDUCTANCE, AND IMPEDANCE OF STANDARD TELEPHONE APPARATUS AT 1000 ALTERNATIONS PER SECOND

Apparatus	S. L. No.	Effective resistance. Ohms	Inductance. Henries	Impedance		Loss in milliwatts per 1 volt
				Ohms	Angle	
Bells.						
1000ω magneto . .	6	7,580	1·305	11,140	47° 9′	·061
Indicators.						
1000ω tubular, ordinary	10	8,000	1·2	11,000	43° 24′	·066
Do. do., differential . . .	11	20,200	·224	20,300	5° 0′	·049
600ω self-restoring .	5	8,055	1·3	11,410	44° 55′	·062
100ω+100ω eyeball signal, unoperated . .	..	3,900	0·512	4,035	14° 45′	240
100ω+100ω eyeball signal, operated . .	..	4,300	0·539	4,440	14° 3′	·219
Instruments.						
Local battery subscribers, battery key up	1	434	0·189	1,265	69° 57′	·027
Do. do., down	1	563	0·182	1,275	63° 48′	·035
Receivers.						
Double pole bell (60ω central battery) .	10	134	0·018	176	40° 24′	4·33
Relays.						
500ω double make-and-break (W.E.) armature not attracted . .	9	7,160	1·157	10,210	44° 54′	·069
Do. do., attracted .	9	7,960	1·238	11,150	44° 24′	·064
1000ω do. do., not attracted . . .	11	9,910	1·543	13,845	44° 18′	·052
Do. do., attracted .	11	9,970	1·617	14,230	45° 30′	·049
Retardation Coils.						
100ω tubular . .	..	1,116	0·191	1,640	47° 6′	·414
200ω ,, . .	..	3,170	0·550	4,690	47° 30′	·144
400ω ,, . .	5	4,700	0·664	6,280	41° 30′	·119
600ω ,, . .	1	5,906	0·890	8,132	43° 20′	·089
1000ω ,, differential	2	19,100	0·538	19,400	10° 0′	·051
75ω+75ω W.E. pattern, No. 2020A .	..	1,827	1·367	8,770	77° 58′	·024
200ω+200ω W.E. toroidal, No.44B .	..	3,600	13·5	85,000	87° 34′	·0005
No. 1, Central Battery Termination (consisting of repeater, supervisory relay, local line and subscriber's instrument).						
(*a*) No. 25 repeater, local line, 0ω .	..	330	0·049	451	42° 57′	1·62
(*b*) Do. do., 300ω (ohmic) . .	..	630	0·068	760	33° 54′	1·09
(*c*) Do. do., 3-m. 20-lb. cable . .	..	680	0·049	746	23° 51′	1·22

Note.—To obtain loss in milliwatts at any voltage V, multiply figures in last column by V^2.

The preceding table is abstracted from an article on "The Impedance of Telephonic Apparatus," by B. S. Cohen, published in *The National Telephone Journal* for September 1909, to which article and one on "Notes on an Instrument for Measuring Inductance," by G. M. B. Shepherd, given in the April 1909 number of the same journal, the reader is referred for full particulars of the methods of measurement by means of alternating currents of high frequency (1000 per second), so as to obtain a very close approximation to the effective resistance and impedance which the various classes of apparatus offer to the rapid alternations of actual speech-transmitting currents.

The measurements have been made at a frequency of 1000 alternations, which with a current strength of from 0·3 to 2 milliamperes has been found to give an equivalent effect to actual speech waves.

It will be seen that the effective resistances and impedances given in the 3rd and 5th columns differ very materially from the ordinary ohmic resistances to continuous current given in the 1st column, and this explains why a comparatively low ohmic resistance shunt, such as a 100 ohm retardation coil, has no appreciable effect on the speaking transmission when joined across even a long line, since the impedance of such a shunt to speech currents is raised more than sixteenfold.

The figures given in column 2 refer to Stock List numbers of the National Telephone Co.'s General Stores Book.

BRITISH STANDARD WIRE GAUGE
AND NEAREST BROWN AND SHARP GAUGE

S.W.G.	Dia. in Mils. — 1 mil. = ·001 in.	Pure Copper Wire at 60° F.				Nearest B. and S. G.	Dia. in Mils.
		Resistance in Ohms		Yards per Ohm	Weight in lbs. per Mile		
		Per Yard	Per Mile				
4	232	·00057	1·00	1760	860	3	229·4
5	212	·00068	1·20	1476	718	4	204·3
6	192	·00083	1·46	1201	589		
7	176	·00099	1·74	1012	495	5	181·9
8	160	·00119	2·10	838	409	6	162
9	144	·00148	2·60	677	331	7	144·3
10	128	·00187	3·29	535	262	8	128·5
11	116	·00228	4·00	438	215	9	114·4
12	104	·00283	4·98	353	173	10	101·4
13	92	·00362	6·37	276	135·3	11	90·74
14	80	·00478	8·42	209	102·3	12	80·81
15	72	·00590	10·39	169	82·9	13	71·96
16	64	·00748	13·16	134	65·5	14	64·08
17	56	·00976	17·18	102	50·1	15	57·07
18	48	·01328	23·38	75·3	36·8	16	50·82
19	40	·0191	33·67	52·4	25·6	18	*40·3
20	36	·0236	41·6	42·4	20·72	19	35·39
21	32	·0300	52·6	33·3	16·37	20	31·96
22	28	·0390	68·7	25·6	12·53	21	28·46
23	24	·0532	93·5	18·8	9·21	22	25·35
24	22	·0638	111·3	15·8	7·73	23	22·57
25	20	·0765	134·7	13·1	6·39	24	20·1
26	18	·0945	166·3	10·6	5·18	25	17·9
27	16·4	·1140	200·4	8·77	4·30	26	15·94
28	14·8	·1400	246	7·14	3·50	27	14·19
29	13·6	·1655	291·3	6	2·96		
30	12·4	·200	350·3	5	2·46	28	12·64
31	11·6	·227	400·4	4·40	2·15	29	11·26
32	10·8	·262	462	3·82	1·86	30	10·02
33	10	·306	538·8	3·27	1·60		
34	9·2	·361	636·6	2·77	1·353	31	8·93
35	8·4	·434	763·6	2·30	1·128	32	7·95
36	7·6	·530	933	1·89	·923	33	7·08
37	6·8	·662	1165	1·51	·739	34	6·3
38	6	·850	1497	1·18	·575	35	5·61
39	5·2	1·132	1992	·885	·432	36	5
40	4·8	1·328	2338	·752	·368		
41	4·4	1·581	2782	·633	·309	37	4·45
42	4	1·913	3367	·523	·256	38	3·96
43	3·6	2·362	4157	·424	·2072	39	3·53
44	3·2	2·990	5262	·334	·1637	40	3·14
45	2·8	3·905	6872	·256	·1253		
46	2·4	5·316	9355	·198	·0921		
47	2	7·654	13470	·131	·0639		
48	1·6	11·95	21040	·0836	·0409	(17	*45·26)
49	1·2	21·26	37420	·0470	·0230		
50	1	30·61	53880	·0326	·0160		

USEFUL NUMBERS

$\pi = \frac{\text{Circumference}}{\text{Diameter}}$ of Circle $= 3{\cdot}1416 = \frac{22}{7}$ nearly.

Circumference (C) of Circle = Diameter $\times \pi$ = Radius (r) $\times 2\pi$.

Diameter (D) of Circle $= \frac{\text{Circumference}}{\pi} = C \times \frac{1}{\pi} = C \times {\cdot}3183$.

Area of Circle $= D^2 \times \frac{\pi}{4} = D^2 \times {\cdot}7854 = r^2 \times \pi$.

Area of Circle in Circular Mils $= D^2 = 4\,r^2$ (D and r being in mils)

Radian = Angle subtended by arc equal to radius = 57·3 degrees.

E = Base of Naperian or Natural Logarithms = 2·7183.

Weight in lbs. of Water = ·036 per cub. in.; 62·4 per cub. ft.; 10 per gallon.

Weight in lbs. of 1 cub. in., of Aluminium = ·096; Copper = ·318; Cast Iron = ·26; Wrought Iron = ·28; Steel = ·288; Lead = ·41; Mercury = ·49; Tin = ·26; Zinc = ·25; Brass = ·3; Bronze = ·316.

One horse-power = 33,000 foot lbs. per minute = 746 watts.

TO CONVERT

Mils to Millimetres × ·0254	Millimetres to Mils × 39·37
Inches to Centimetres × 2·54	Centimetres to Inches × ·3937
Feet to Metres × ·3048	Metres to Feet × 3·281
Square Inches to Sq. CMS × 6·452	Sq. CMS to Sq. Ins. × ·155
Cubic Inches to Cubic CMS × 16·387	Cubic CMS to Cub. Ins. × ·061
Ounces to Grammes × 28·35	Grammes to Ounces × ·0353
Pounds (7000 grains) to Kilogrammes × ·4536	Kilogrammes to Pounds × 2·205
Ohms per Yard to Ohms per Metre × 1·0936	Ohms per Metre to Ohms per Yard × ·9144
Ohms per Mile to Ohms per Kilometre × ·6214	Ohms per Kilometre to Ohms per Mile × 1·609

Degrees Fahrenheit to Centigrade deduct 32 × 5 and ÷ 9.

Degrees Centigrade to Fahrenheit × 9 ÷ 5 and add 32.

Naperian Logs. to Common Logs. × ·4343.

Common Logs. to Naperian Logs. × 2·303.

INDEX

C

D

E

P

R

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4 WEEKS